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ATTRIBUTES OF COMPLEX TONES *

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I. INTRODUCTION

The characteristics of complex tones which are commonly denoted by the term timbre have never been rigidly determined or defined. Musicians use a loose and variable terminology in describing their tonal experiences, and psychologists have done little more than to describe the general and superficial aspects of a few simple types of complex tones. Because adequate information on timbre was lacking, the present investigation was undertaken. Its specific purpose was to discover whether or not complex tones have identifiable attributes other than pitch and loudness.

It is generally admitted that all tones, both complex and pure, have the attributes of pitch and loudness. There have been differences of opinion, however, as to whether complex tones possess an attribute of timbre or any attributes other than those of pure tones. One group of investigators has held that a complex tone is nothing more than a combination or blend of pure tones. On the other hand, current writers in general psychology and in acoustics often list timbre as one of the three basic characteristics of tone. The first view is an outgrowth of Ohm's law of acoustics. This law combines a knowledge of the physical nature of complex tones with certain facts of auditory analysis, and states, in effect, that each simple vibration in the stimulus gives rise to a simple tone which may be heard individually. The knowledge that a complex tone consists of numerous simple vibrations and that trained observers can hear some of these as simple tones seems to underlie the belief that all complex tones can be accounted for psychologically as combinations of simple

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tones. Whether or not the data concerning auditory analysis warrant this conclusion is open to question.

It is true that competent observers can 'hear out,' in turn, the partials of some complex tones, but the difficulty and slowness of this process have been pointed out. Helmholtz (**4**) notes the 'considerable difficulty' experienced by one who first attempts to hear the individual partials. Titchener (**12**) reports an experiment in which, under the most favourable conditions, it took up to twenty minutes for observers to hear the third partial individually. In the present experiment, on the other hand, complex tones were discriminated on the basis of timbre when the duration of the tones was only two seconds, and the data indicate that many of the discriminations were easily made.

The investigation proceeded on the assumption that complex tones are usually heard as single and that they have fundamental characteristics denoted by the term timbre. The tones discriminated in this experiment were equated in loudness; and measurements showed that, for the observers used, the tones did not differ significantly in pitch. They must have differed, therefore, in some attribute or attributes other than pitch and loudness. It was the purpose of this study to determine those attributes.

Boring (**2**) has suggested two criteria by which an attribute may be established. The first of these is independent variability. This requires that the proposed attribute be a different function of stimulus variables from that of any other attribute. The second criterion requires that the attributes be sufficiently different so that discrimination between them does not become difficult. Subsequent discussion will attempt to show that complex tones have attributes, aside from pitch and loudness, which probably satisfy these criteria.

II. Apparatus

The complex tones used in the investigation were produced with a multiharmonic generator of electrostatic type, the basic features of which have been described by Kurtz and Larsen (5) and by Lewis and Larsen (**6**). This instrument generates electrical currents which, after amplification, are capable of producing (in loudspeaker or phones) complex tones containing as many as 16 consecutive harmonic partials. In the tones studied, the fundamental frequency was set at either 130 or 180 cycles. The intensity level and phase angle of each partial were subject to control.

The output of the generator could be led into a Western Electric 555 receiver in an acoustically treated 'dead' (nonreverberant) room for listening by a single subject, or it could be led to the phonograph recording studio. A vacuum tube voltmeter in the output circuit of the generator made possible the measurement of the intensity of the various harmonics. In this way, the generator could be calibrated. This was done each time it was used. The Western Electric receiver had previously been calibrated by the Bell Telephone Laboratories. The over-all response of the recording equipment was determined several times during the course of the study. This was done by recording each of the 16 partials at equal input intensity and then measuring the amplitude of response on the record by means of the light-band method. This method has been described by Buchman and Meyer (**3**). Each setting for any given tone

spectrum took into account the output characteristics of the generator as well as the response characteristics of the particular system being used.

Many of the complex tones were presented to the observers from phonograph records. In the preparation of the records, the generator was successively set to produce the various tones and these tones were recorded separately on acetate disks. The records were played on a Magnovox Concerto phonograph, and the tones thus produced were the ones judged by the subjects. The response curve for this phonograph is given by Saetveit (**8**). Each series of tones used was recorded four separate times. In the course of the experiment, no record was played often enough to cause any marked change in the nature of the tones reproduced.

Practical considerations dictated the use of the phonographic technique. A more accurate set of stimuli would have been obtained if the generator output had been connected to the phone in the 'dead' room and the subjects had listened there. This would have necessitated apparatus to make possible a rapid switching of the generator from one tone to another. While such equipment is possible, its extreme elaborateness precluded its use in the present experiment. The use of the recording and phonographic technique undoubtedly introduced some amount of error. It is felt, however, that with the precautions taken, this error was not large enough to affect the results. The stimuli used probably did not differ greatly from those intended.

Other equipment was used in certain control experiments. It will be described when those experiments are discussed.

III. Procedure and Results

The first problem was to find different series of tones each of which seemed to demonstrate a basic type of change in quality or timbre, to obtain a psychological scale for each series, and to state the relations between the stimuli and the responses. Preliminary observations indicated that a seemingly important type of qualitative change, tentatively labelled *dullness-brightness*, could be obtained by means of a series of tones in which the midpoint of the energy distribution was gradually shifted upward along the frequency continuum. A particular method of changing the location of the midpoint of the energy was then adopted and a series of tones, the spectra of which are shown in Fig. 1, was chosen to be scaled.

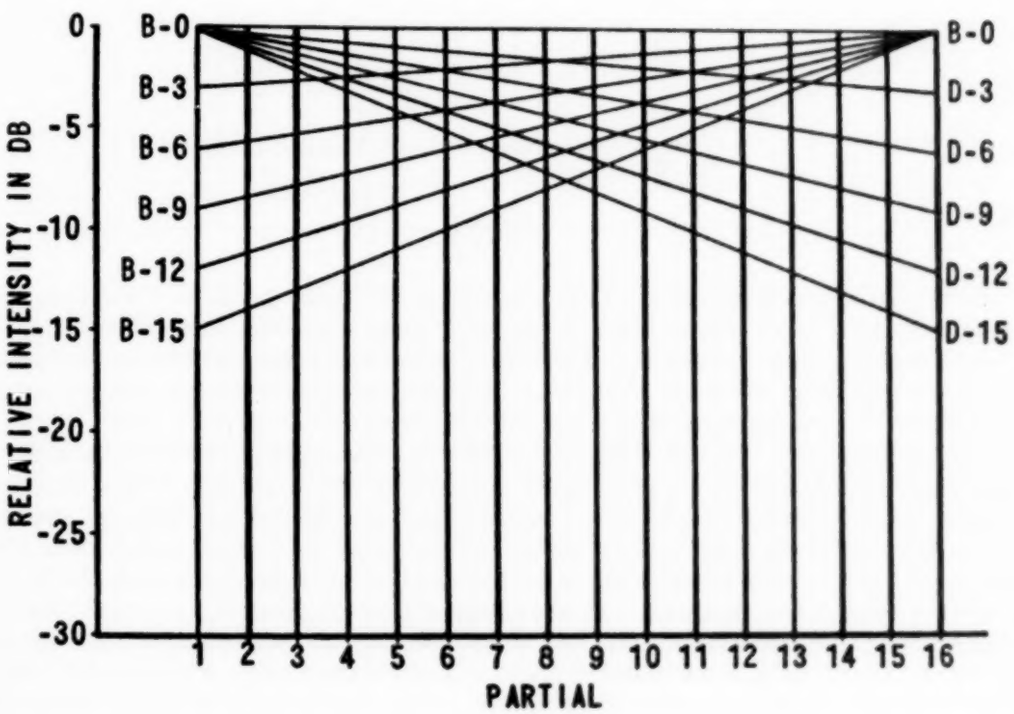

Fig. 1. The relative intensities of the partials in each tone of the D–B series. The points at which a contour-line intersects the vertical lines indicate the relative intensities of the partials in that tone. The designation of the tone is given at one end of the contour.

In this figure, the relative intensities of the partials of each tone are shown. Each contour-line represents the spectrum of one tone in the series. The points at which a given contour intersects the vertical lines for the various partials indicate the relative intensities of those partials in that tone. The figure does not indicate the intensity of one tone as compared with another, nor does it indicate the absolute intensity of a partial in one tone as compared with its absolute intensity in another. The contour for tone D–15 indicates that the 16th partial was 15 db less intense than the fundamental, the 15th partial was 14 db less intense than the fundamental, the 14th partial 13 db less intense, etc. In tone B–15, the 1st partial (fundamental) was 15 db less intense than the 16th, the 2nd partial 14 db less than the 16th, etc. In designating these tones, the letter indicates the direction of the slope of the spectrum and the numeral indicates the difference in db between the most intense and least intense partials. This series of tones will be referred to as the D–B series.

TABLE 1

SCALE VALUES FOR THE D–B SERIES OF TONES, FOR THE FINAL GROUP OF OBSERVERS

Tone	Diff.	Scale (D–15 = .00)	Scale (B–0 = .00)
D–15		.00	−2.65
	.47		
D–12		.47	−2.18
	.29		
D–9		.76	−1.89
	.71		
D–6		1.47	−1.18
	.39		
D–3		1.86	− .79
	.79		
B–0		(2.65)	(.00)
	.79		
B–3		3.45	.79
	.65		
B–6		4.09	1.44
	.56		
B–9		4.65	2.00
	.47		
B–12		5.12	2.47
	.49		
B–15		5.61	2.96

When this series was recorded, the intensity level of each tone was adjusted so that all tones sounded equally loud when played from the record. Judgments from three observers were the basis for determining these intensities. Each tone of the series was recorded for a duration of about two seconds. The onset and cessation of the tones were made gradual enough to prevent transient effects. The fundamental frequency was 180 cycles.

A psychological scale of these tones was obtained. The series was scaled by the method of paired comparisons, first with a preliminary group of 25 observers, then with a final group of 255. The subjects were students, most of them undergraduate, in music, speech, and psychology. For the preliminary group, each tone in the series was paired with every other tone. For the final group, each tone was paired with not more than four other tones, these being the two neighboring tones on each side in the series. The number of intercomparisons in the final scaling was restricted because the preliminary work had shown that the pairs eliminated were very easily discriminated. The results were therefore useless in the computation of the scale. For both groups of observers, each of the pairs was presented twice, the order of members being reversed the second time.

The subjects who were used for the final scaling were handled in groups ranging in size from 7 to 40. Each group made at one sitting all the judgments required in connection with the scaling of the D–B series and of two other series, which will be mentioned later. The total

time required was about 45 minutes. All possible orders for the three groups of judgments (relating to the three series) were used, each about the same number of times. Within each of these groups, three orders of pairs were used, about an equal number of subjects being given each order.

The procedure in obtaining judgments was as follows: A representative sample of tones from the series was played to give the subjects a general survey. Tones B–15 and B–12 were then played several times and the subjects were instructed that these tones should be taken as arbitrarily defining the term 'bright.' Tones D–15 and D–12 were then played several times and the subjects were instructed that these tones should be taken as arbitrarily defining the

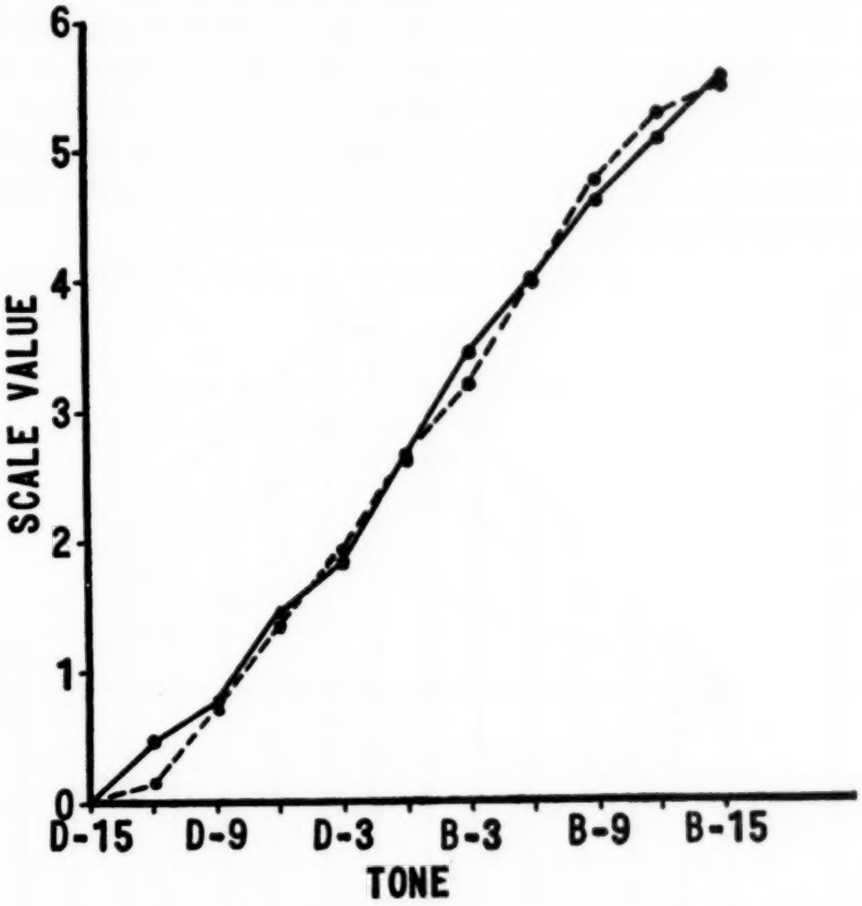

FIG. 2. Scale values for the tones of the D–B series. The dotted line connects the values obtained when the series was scaled with the preliminary group; the solid line connects the values obtained when the series was scaled with the final group.

term 'dull.' B–15 and D–15 were then played alternately several times. The subjects were then told that they would hear pairs of tones and that they were to indicate after each pair whether the second member was 'brighter' or 'duller' than the first. They were told to guess, if necessary, and to make a response for each pair. In the course of the judgments, the criterion was not given again except in a few instances when the subjects felt uncertain about it.

From the data obtained, the scale values were computed according to the method of Thurstone (11), Case V. The values for the final scale are shown in Table 1. The first column designates the tones of the series, the second column gives the scale distances between adjacent tones in the series, the third gives the scale values when D–15 is the zero point, and the last column gives the scale values from an arbitrary zero point. In Fig. 2, the scale values are plotted against stimulus values. The preliminary scale is also shown.

It will be noticed that the value for the B–0 tone is given in parenthesis in Table 1. It has been mentioned that the D–B series

was recorded four times. In two of the four recordings, the B–o tone was later discovered to be defective. This made it necessary to omit from the computations the data on all pairs in which the B–o tone occurred. As a result, there is no scale value for this tone. It has arbitrarily been given a value halfway between those of tones D–3 and B–3. This value, 2.65, corresponds very closely to the value of B–o in the preliminary scale, which was 2.67. (This arbitrary location of B–o has been taken as the zero point for the scale as given in the last column of Table 1.) Because the preliminary and final scales show a close agreement, it seems reasonable to accept this value for B–o as a good estimate. The similarity of the two scales suggests that the necessary omission of data on pairs containing the B–o tone did not result in a serious defect in the final scale. The reliability of the scale will be discussed later.

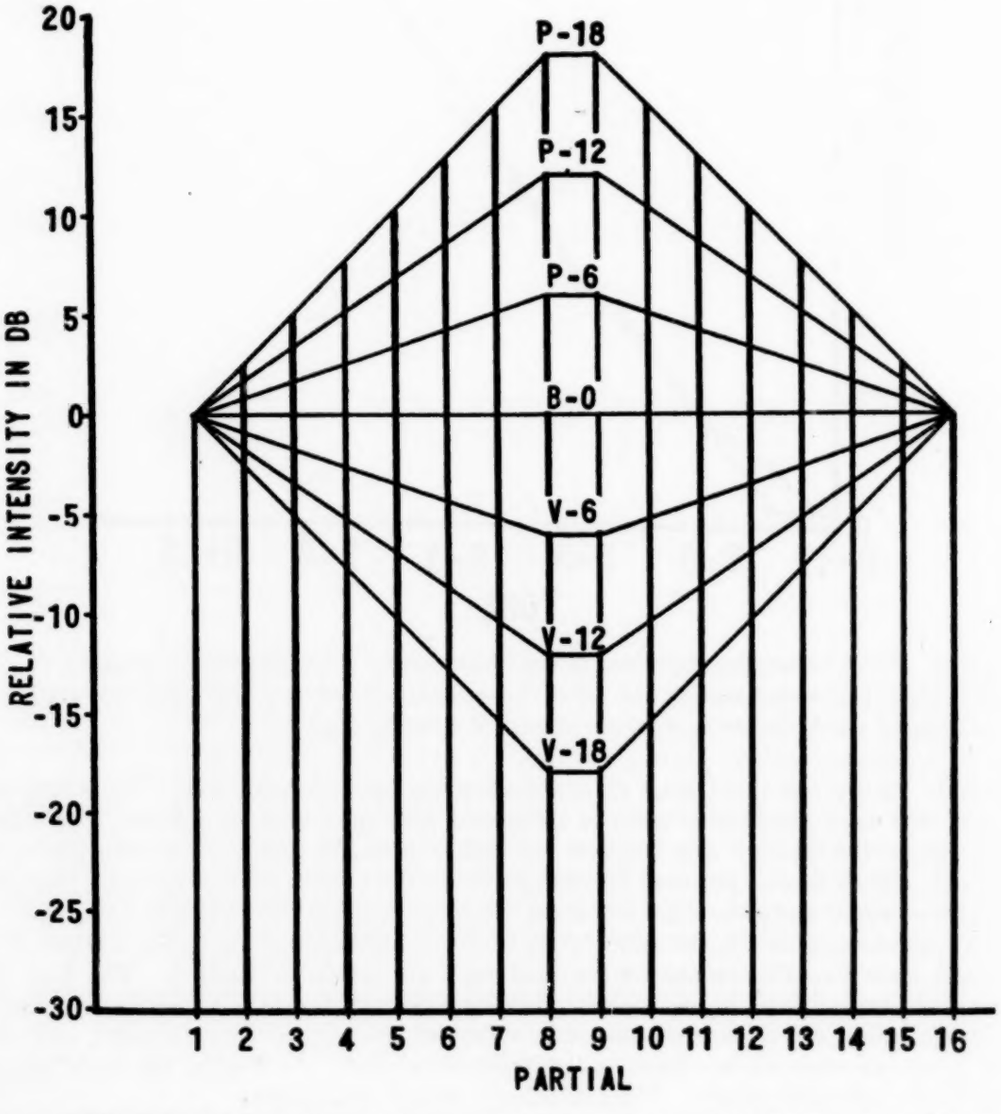

FIG. 3. The relative intensities of the partials in each tone of the V–P series. The points at which a contour intersects the vertical lines indicate the relative intensities of the partials in that tone. The designation of the tone is given with each contour.

The physical nature of another series of tones which was scaled is indicated in Fig. 3. Again the figure shows only the relative intensities of the partials of each tone. Each contour represents the spectrum of a single tone. In the designation of the tones, the letter indicates the type of spectrum (*V* for V-shaped and *P* for peaked), and the numeral indicates the number of db by which the intensity of the two middle partials differs from that of the first and sixteenth partials. This series will be called the V–P series. A series of this type was scaled with the preliminary group of 25 subjects. On the basis of these results, the particular stimulus values shown in Fig. 3 were selected for use in the final scaling. The subjects and the procedure used in scaling this series were the same as those used in scaling the D–B series, except that each tone was paired with every other tone in the series. The terms 'bright' and 'dull' were used again because the V–P series sounded much like the D–B series.

TABLE 2

SCALE VALUES FOR THE V–P SERIES OF TONES

Tone	Diff.	Scale (V–18 = .00)	Scale (B–0 = .00)
V–18		.00	−.51
	.12		
V–12		.12	−.39
	.20		
V–6		.33	−.19
	.19		
B–0		.51	.00
	.31		
P–6		.82	.31
	.58		
P–12		1.41	.89
	.26		
P–18		1.67	1.16

Computations from the data (Thurstone's Method, Case V) yielded the scale values given in Table 2. The first column designates the tones, the second gives the scale distances between adjacent tones in the series, the third gives the scale values when V–18 is the zero point, and the fourth gives the values when B–0 is the zero point. In Fig. 4, scale values are plotted against stimulus values. The curve is very slightly sigmoid, and it will be noted that the scale is of small magnitude.

One other series was scaled. The series consisted of five tones, labelled O–18, O–9, B–0, E–9, and E–18. The nature of these tones was as follows: There were 16 partials in each tone of the series. In tone O–18, the odd-numbered partials were at one level of intensity and the even-numbered partials were all at another level, the former

being 18 db more intense than the latter. In tone O–9, the odd-numbered partials were 9 db more intense than the even-numbered partials. The B–o tone was the same as the B–o tones in the other series. In E–18, the intensity level of the even-numbered partials *and the fundamental* was 18 db greater than that of the odd-numbered partials (other than the fundamental). In E–9, the even-numbered partials and the fundamental were 9 db more intense than the other

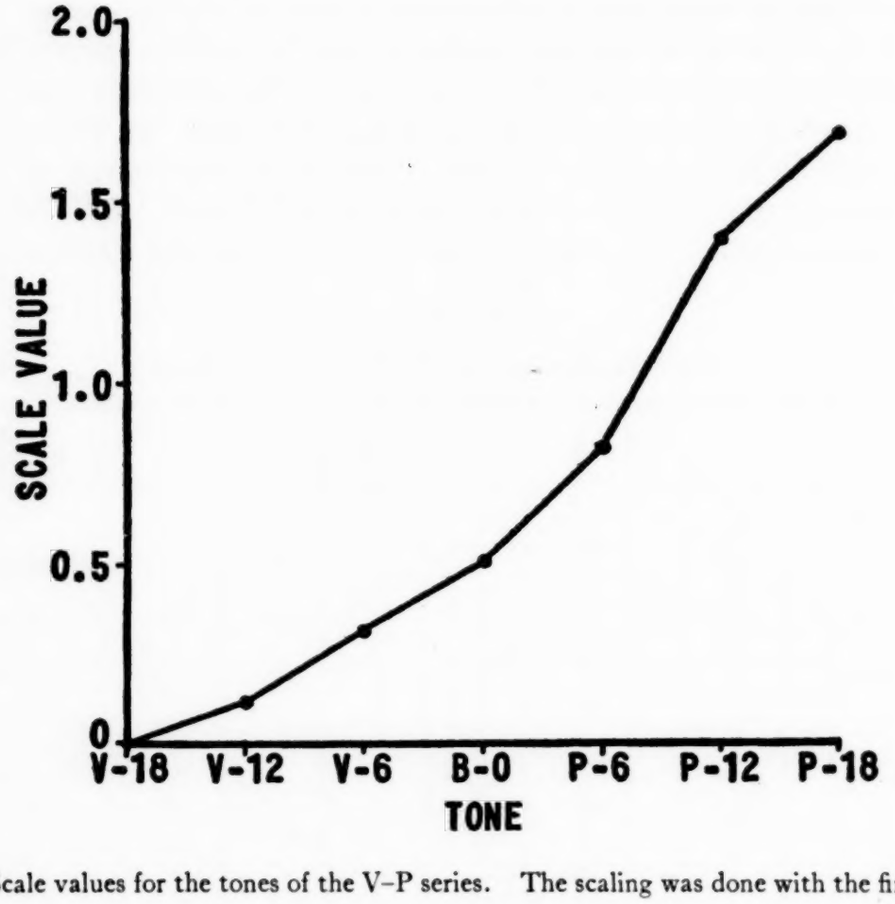

FIG. 4. Scale values for the tones of the V–P series. The scaling was done with the final group.

partials. There was an important reason for keeping the intensity of the fundamental at a high level in the E tones. The frequencies of the even-numbered partials were integral multiples of the frequency of the second partial, thus they formed a harmonic series to which the second partial was the fundamental. When the intensity of the fundamental (first partial) was weak, the primary pitch of the E tones seemed to be that of the second partial. It was to avoid this effect that the intensity of the fundamental component was made equal to that of the even-numbered partials. These tones will be referred to as the E–O series.

The method of paired comparisons was again used, each tone being paired with every other tone. Subjects and procedures were the

same as for the other series except that the terms 'thin' and 'full' were used. Tone E–18 was used as an arbitrary definition of the term 'thin,' and O–18 as 'full.' The scale distances and scale values are shown in Table 3. The scale is plotted in Fig. 5. The data show that there is a reversal, O–18 having a smaller scale value than O–9.

The reliabilities of these three scales were estimated by comparing the obtained proportions with the proportions theoretically demanded by the scale. (A proportion is the percent of times that one tone of a pair was judged brighter [or thinner] than the other member.)

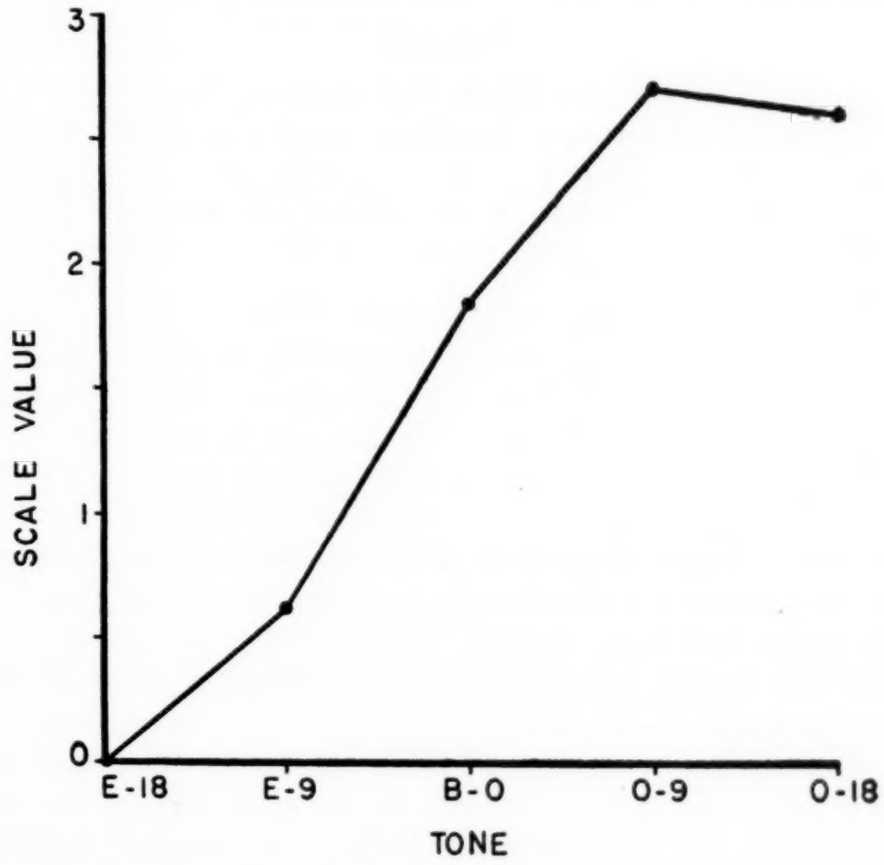

FIG. 5. Scale values for the tones of the E–O series. The scaling was done with the final group.

An unreliable scale distance is indicated if a discrepancy between theoretical and obtained proportions is larger than .07, which is four times the probable error of a representative obtained proportion (N = 255). The mean discrepancies between the observed and theoretical proportions for the D–B, V–P, and E–O scales were .032, .054, and .027, respectively. The first and third are of about the same magnitude as the mean discrepancy reported by Thurstone (11). The number of individual discrepancies greater than .07 was two, seven, and one, for the D–B, V–P, and E–O scales, respectively. The reversal of the two tones in the E–O series was unreliable.

The reliability of the three scales, particularly that of the scale for the V–P series, could probably have been increased through the use of Thurstone's Case III or Case IV. It was felt, however, that for the purpose of this study the additional refinement was not necessary. The scales are considered to be sufficiently accurate to serve as a basis for the conclusions to be drawn from them. These conclusions are based on the general nature of the scales rather than on scale distances between specific tones. The general form of the second scale is probably essentially correct. The reliability of the third scale is good except for the reversal. The reliability of the first scale is acceptable.

TABLE 3

SCALE VALUES FOR THE E–O SERIES OF TONES

Tone	Diff.	Scale (E–18 = .00)	Scale (B–o = .00)
E–18		.00	−1.85
	.62		
E–9		.62	−1.23
	1.23		
B–o		1.85	.00
	.86		
O–9		2.72	.86
	−.10		
O–18		2.61	.76

After these scales had been derived, an attempt was made to evaluate the second and third series in terms of the criterion by which the D–B series had been judged. Specifically, the problem was to determine the degree of brightness (as defined by the D–B series) possessed by tones V–18, P–18, E–18, and O–9, these being the extremes of the other two series. In order to do this, each of these tones was paired with tones of the D–B series, and observers were asked to judge, for each pair, whether the second member was brighter or duller than the first. A study of Table 4 will show what tones were paired and the percentage of times that the tones in question were judged brighter than the paired tones from the D–B series. Each pair referred to by the figures in the upper four rows of the table was judged six times by each of 69 subjects.

The most difficult pairs to judge were those containing tone E–18. This was probably due to the fact that E–18 sounded as if it consisted of two somewhat separate tones, the fundamental and a tone an octave higher. The reason for this effect has been mentioned, namely that the even-numbered partials formed a harmonic series to which the second partial was a fundamental. The difficulty of judgment is reflected in the figures for E–18 in the row next to the

bottom in Table 4. The percentages are not greatly different for the different pairs.

Another test to determine the brightness of E–18 was carried out. The method was improved by re-establishing the criterion of judgment after each pair containing E–18. This was done by inserting a trial which required a judgment on two easily discriminable tones from the D–B series. The resulting data are given in Table 4

TABLE 4

PERCENTAGE OF TIMES TONE IN LEFT-HAND COLUMN WAS JUDGED BRIGHTER THAN TONE IN TOP ROW

Tone	B–15	B–12	B–9	B–6	B–3	D–3	D–6	D–9	D–12
V–18					17	43	62		
P–18		19	26	39	47				
O–9						23	41	51	67
E–18					61	69	72		
E–18 (2nd)	23		29		39	51			

after E–18 (2nd). These results were obtained from 35 subjects. Each subject made 12 judgments per pair.

Linear interpolation of the data in Table 4 (extrapolation in the case of P–18) yielded the values given in Table 5. The brightness of each of the tones is given in terms of the D–B scale. The point for E–18 was computed from the data obtained in the second test. The significance of these data will be discussed later.

TABLE 5

POINTS OF SUBJECTIVE EQUALITY IN BRIGHTNESS FOR V–18, P–18, O–9, AND E–18, GIVEN IN TERMS OF SCALE VALUES OF THE D–B SERIES

Tone	Scale Values (B–0 = .00)	Scale Values (D–15 = .00)
V–18	− .94	1.72
P–18	.55	3.20
O–9	−1.82	.83
E–18	− .66	1.99

IV. CONTROL EXPERIMENTS

A. Pitch Matching

It has been stated that the pitch of a complex tone may change with changes in its structure. Bannister says: "The more pronounced the overtones, especially the higher ones, the higher the pitch appears to be" (1, page 894). If this were true, it might be maintained that the judgments on which these scales were based were actually judgments of pitch differences between the tones. The purpose of the first of these controls was to determine whether the

pitch of the complex tones in these series varied with the change in structure. The general procedure was to measure the pitch of the complex tones by matching them in pitch with a pure tone. When the complex tone and the pure tone sounded equal in pitch, the frequency of the pure tone was taken as a measure of the pitch of the complex tone.

The apparatus was arranged so that the output of the tone generator and that of a beat frequency oscillator were both led to the receiver (earphone) through a double-throw foot switch. When the switch made contact in one position, the output of the generator was connected with the receiver. Contact with the switch in the other position connected the output of the beat frequency oscillator with the receiver. (A GR type 613–B oscillator was used along with a GR type 546–A microvolter and a GR type 539–S variable [incremental frequency] air condenser.) The outputs of the two sources were also led directly to the horizontal and vertical plates, respectively, of a cathode-ray oscilloscope. By means of Lissajou figures on the oscilloscope, the frequency of the oscillator could be set equal to the fundamental frequency of the complex tone. The frequency of the oscillator could be varied either by means of the main dial or the incremental condenser. The *loudness level* of the oscillator tone was 40 db at 180 cycles. The *intensity level* of the most intense partial in the complex tone was 60 db, the intensities of the other partials being determined by the structure of the tone. Subject and experimenter were in a nonreverberant room.

The task of the subject was to listen alternately to the two tones and to adjust the frequency of the pure tone until the two sounded equal in pitch. The experimenter then recorded the frequency of the pure tone in cycles per second above or below the fundamental frequency of the complex tone. Before each ten trials, the frequency of the oscillator (at zero setting of the incremental frequency condenser) was set equal to the fundamental frequency of the generator. After each ten trials, any change in the relative frequencies of the two sources was measured, and the recorded judgments were corrected accordingly. It was assumed that any change in the relative frequencies of the two sources took place at a uniform rate.

The subjects were graduate students in psychology. Each individual made 100 judgments on each of two tones. On the first day, 50 judgments were made on tone A and 50 on tone B, in that order. On the second day, there were first 50 on tone B and then 50 on tone A. The two complex tones matched by any one subject were either B–15 and D–15, P–14 and V–14, or E–30 and O–30. These tones were the extreme ones of the three scaled series, or tones similar to them. The last four tones listed differed somewhat from the extreme tones of the V–P and E–O series because the matching was done before the final forms of these series had been determined.

TABLE 6

RESULTS FOR INDIVIDUALS AND GROUP WHEN A PURE TONE WAS MATCHED IN PITCH TO TONES B–15 AND D–15. MEANS REPRESENT THE AVERAGE FREQUENCY OF THE PURE TONE IN CYCLES PER SECOND ABOVE OR BELOW THE FUNDAMENTAL FREQUENCY OF THE COMPLEX TONE

S	Mean (B–15)	σMean	Mean (D–15)	σMean	Diff. (B − D)	σDiff.	C.R.
Bi	− .35	1.35	14.36	1.18	−14.71	1.79	8.22
Fe	2.53	.88	−2.55	.41	5.08	.98	5.18
Gu	−3.32	.31	−3.50	.27	.18	.40	.45
Je	1.93	.69	.64	.46	1.29	.82	1.57
Mc	5.65	.77	2.05	.35	3.60	.84	4.29
Me	− .59	.16	− .71	.11	.12	.20	.60
Mi	−6.51	.21	−7.00	.19	.49	.28	1.75
Sa	.34	.28	.92	.15	−.58	.30	1.93
Group *	− .04	1.31	.53	2.26	−.57	2.61	.22

* Computed according to the formula for the Fisher *t* test (N = 8).

Table 6 presents the results for the eight subjects who matched the pitches of tones B–15 and D–15. Each value indicates the mean frequency of the pure tone, when equal in pitch to the complex tone. This mean is given in cycles per second above or below the fundamental frequency of the complex tone. Thus, when subject Je had adjusted the frequency of the pure tone until its pitch seemed equal to the pitch of the complex tone, the frequency of the pure tone was, on the average, 1.93 cycles higher than the fundamental frequency of the complex tone. This value may be taken as a measure of the pitch of tone B–15, as heard by Je. It may be compared with the value of .64 cycle representing the pitch of tone D–15 for the same subject. For this subject, the two complex tones differed in pitch by 1.29 cycles.

TABLE 7

RESULTS FOR INDIVIDUALS AND GROUP WHEN A PURE TONE WAS MATCHED IN PITCH TO TONES P–14 AND V–14. MEANS REPRESENT THE AVERAGE FREQUENCY OF THE PURE TONE IN CYCLES PER SECOND ABOVE OR BELOW THE FUNDAMENTAL FREQUENCY OF THE COMPLEX TONE

S	Mean (P–14)	σMean	Mean (V–14)	σMean	Diff. (P − V)	σDiff.	C.R.
Ho	12.73	1.07	4.76	.83	7.97	1.35	5.91
Ir	−2.97	.16	−1.97	.13	−1.00	.21	4.75
Li	18.73	.66	1.78	.77	16.95	1.01	16.78
Pa	−1.21	.20	−2.47	.15	1.26	.25	5.04
Sl	−3.01	.55	1.84	.50	−4.85	.74	6.55
Sp	−4.35	.63	−4.96	.30	.61	.69	.88
Ta	−2.84	.24	−1.60	.24	−1.24	.34	3.65
Group *	2.44	3.24	− .37	1.16	2.81	3.44	.82

* Computed according to the formula for the Fisher *t* test (N = 7).

TABLE 8

RESULTS FOR INDIVIDUALS AND GROUP WHEN A PURE TONE WAS MATCHED IN PITCH TO TONES E–30 AND O–30. MEANS REPRESENT THE AVERAGE FREQUENCY OF THE PURE TONE IN CYCLES PER SECOND ABOVE OR BELOW THE FUNDAMENTAL FREQUENCY OF THE COMPLEX TONE

S	Mean (E–30)	σMean	Mean (O–30)	σMean	Diff. (E − O)	σDiff.	C.R.
Ch	3.44	1.47	3.49	.86	− .05	1.70	.03
Da	−1.83	.27	− .92	.33	− .91	.42	2.17
Di	1.44	.13	1.71	.14	− .27	.20	1.35
Gr	1.95	.32	− .70	.31	2.65	.46	5.76
Ha	−2.31	.12	− .70	.14	−1.61	.18	8.94
Ri	− .15	.49	−4.55	.38	4.40	.56	7.86
Wa	− .86	.18	−1.37	.20	.51	.27	1.89
Wi	−2.69	.76	−5.33	.22	2.64	.79	3.34
Group *	− .13	.77	−1.05	1.03	.92	1.28	.72

* Computed according to the formula for the Fisher *t* test (N = 8).

Results for the group are given in the bottom row of figures in the table. The reliability of the difference was computed with the formula for the Fisher *t* test. The difference, 1.57 cycles, is not as large as its standard error; therefore the two tones did not differ significantly in pitch for the group. For subject Fe and Mc, tone B–15 was significantly higher in pitch than D–15. For subject Bi, there was a significant difference in the opposite direction. However, the standard errors of the means are rather large for these three subjects.

Tables 7 and 8 show the same type of data for the other two pairs of tones. To summarize the three tables: For two of these three groups, the difference between the means for the two tones was less

TABLE 9

RESULTS FOR INDIVIDUALS WHEN A PURE TONE WAS MATCHED IN PITCH TO TONES B–15 AND D–15, AT FUNDAMENTAL FREQUENCIES OF 360 AND 540 CYCLES

Means Represent the Average Frequency of the Pure Tone in Cycles per Second Above or Below the Fundamental Frequency of the Complex Tone.

S	Mean (B–15)	σMean	Mean (D–15)	σMean	Diff. (B – D)	σDiff.	C.R.
A. Fundamental Frequency = 360 Cycles							
Di	– .10	.13	.42	.16	– .52	.21	2.48
Pa	– .88	.16	– .61	.14	– .27	.22	1.23
Sp	1.36	.22	3.29	.33	–1.93	.40	4.82
B. Fundamental Frequency = 540 Cycles							
Me	1.71	.13	2.52	.12	– .81	.18	4.50
Sa	1.67	.13	3.37	.15	–1.70	.20	8.50
Ta	.94	.18	2.31	.15	–1.37	.23	5.96

than one cycle. For all three groups, the difference was not as large as its standard error. In each group, there were individuals for whom the two tones differed significantly in pitch, but these differences were not consistent as to direction in any group, and many such subjects had high standard errors of means. These results therefore indicate that the changes in harmonic structure in these three series had no consistent and significant effect on the pitch of the tones.

This conclusion holds only for these tones at the frequency of 180 cycles. Any broad generalization that harmonic structure does not affect pitch is made impossible by results obtained with tones D–15 and B–15 at fundamental frequencies of 360 and 540 cycles. The two tones at the frequency of 360 cycles contained only eight partials, and the two at 540 cycles contained only five partials.

At each frequency, each of three observers made 100 judgments on tone D–15 and 100 on tone B–15. The data are presented in Table 9. It can be seen that in every case, tone D–15 was higher in pitch than B–15. (For the group who judged these two tones at the frequency of 180 cycles, the difference was in the same direction.) Four of the differences are statistically significant, one is very nearly so, and one is not significant. Why the tone with the greatest emphasis on the high partials should be the lower of the two in pitch is difficult to explain. These results are a contradiction of Bannister's statement, previously quoted. They show that only limited conclusions can be drawn from the data obtained for the frequency of 180 cycles.

It should be noted in passing that a given complex tone may differ significantly in pitch for two individuals judging it. In Table 6 it may be seen, for example, that tone B–15 differed in pitch by 6.85 cycles for subjects Sa and Mi. The standard error of the difference is only .35 cycle. Table 7 shows that for subjects Pa and Sl, tone V–14 differed in pitch by 4.31 cycles with a standard error of .52 cycle. Table 8 shows that for subjects Di and Ha, tone E–30 differed in pitch by 3.75 cycles while the standard error is .17 cycle. All these differences are statistically significant by a wide margin, and other such differences can be found. The data also show that the mean frequency of the pure tone differed significantly from the fundamental frequency of the complex tone of equal pitch in 36 out of the 46 instances. (The median significant difference was −1.37 cycles; Q was 2.43 cycles.) An explanation of these results would be of great theoretical interest.

It may also be of importance to note that, for the individuals who matched the complex tones at a frequency of 180 cycles, the effect of practice seemed to be to lower the pitch of the complex tone. Means for the first 50 and for the last 50 judgments of all individuals were computed. The mean (for the total group) of the last 50 judgments was 1.26 cycles lower than the mean of the first 50 judgments. The mean of the last 20 judgments was 2.23 cycles lower than that of the first 20. This evidence suggests that the pitch of complex tones may be higher for an unpracticed or naive listener than it is for a practiced or sophisticated listener. Such facts might give rise to the statement made by Bannister concerning the effect of complexity on pitch. For each group, such effects were counterbalanced for the two tones.

B. Quality Matching

The matching technique was also used to investigate the possibility of a relationship between pitch and brightness. An attempt was made to see whether the brightness of a complex tone could be

expressed or matched by a pure tone or, in other words, whether a pure tone could be equated, by being adjusted in frequency, to the quality of a complex tone. The task of the subjects was to listen alternately to a pure and a complex tone, and to set the pure tone at the frequency at which it best matched the timbre or quality of the complex tone.

Two complex tones differing considerably in brightness were matched. The structure of each is indicated in Table 10. The numbers show the intensity of each partial in db below the level of the most intense partial. The tone with the region of energy peaking sharply at the third partial was somewhat smooth and dull. The tone with the region of energy peaking sharply at the eighth partial was bright and 'nasal.' In each tone, the intensity level of the most intense partial was 70 db. The pure tone was set at a level of intensity which made it sound, for the subject, equal in loudness to the

TABLE 10

RELATIVE INTENSITIES OF PARTIALS IN COMPLEX TONES USED IN THE 'QUALITY MATCHING' SERIES

The Intensity of Each Partial Is Given in db Below the Level of the Most Intense Partial.

Partial	1	2	3	4	5	6	7	8	9	10
Tone A...	10.4	13.2	*0.0*	13.6	19.9	23.4	25.4	26.9	28.4	30.4
Tone B...	12.0	21.0	26.5	30.0	29.0	24.5	17.0	*0.0*	14.5	19.5

complex tone. The fundamental frequency of the complex tones was 133.3 cycles. The apparatus was similar to that used for the pitch matching except that a different frequency-measuring system, known to be accurate, was used.

The seven subjects used can be divided into two groups. One group consisted of three graduate students in psychology who had had several years of advanced musical training. Each of these subjects persisted in matching the fundamental frequency of the complex tone. They reported that the quality match was almost equally good over a wide range of settings, and that pitch similarity became the deciding factor in making the qualities most nearly equal.

The other four subjects had had little or no musical training. All were students in psychology; three were graduate students. Each of these subjects made 50 judgments in each complex tone. The distribution of the settings is given in Table 11. The table shows, for each subject and for the group, the percentage of settings falling into each class interval. The size of the class interval is 66.65 cycles and the midpoints of alternate intervals are at the frequencies of partials in the complex tone. The frequencies of the midpoints

of the intervals are given in the first column of the table. The indented numerals indicate interval midpoints halfway between the frequencies of two consecutive partials. The frequencies of the third and eighth partials (those of greatest intensity in tones A and B, respectively) are italicized.

A study of the table will reveal a few vague trends in the data: The settings of subject Eg were fairly consistent and seem to have been a compromise between the pitch of the fundamental and that of the prominent partial in the tone. All the subjects, possibly

TABLE 11

PERCENTAGE OF JUDGMENTS, FOR INDIVIDUALS AND GROUP, FALLING INTO EACH CLASS INTERVAL WHEN A PURE TONE WAS MATCHED IN QUALITY TO COMPLEX TONES

Subject	Eg		Lo		Ni		Gr		Group	
Tone	A	B	A	B	A	B	A	B	A	B
Frequency of Interval Midpoint										
133.3			4	10	6	2	2		3.0	3.0
199.9	8			4			8	4	4.0	2.0
266.6	64		28	8	22	10	4	4	29.5	5.5
333.2	22				2		8	14	8.0	3.5
399.9	6						24	16	4.5	4.0
466.5							14	6	3.5	1.5
533.2		80	28	16	70	84	20	16	29.5	49.0
599.8				2			12	8	3.0	2.5
666.5		6					8	6	2.0	3.0
733.1		10		2				6		4.5
799.8								2		0.5
866.4								6		1.5
933.1								2		0.5
999.7								2		0.5
1066.4		4	40	54		4		4	10.0	25.5
1133.0										
1199.7										
above 1250								4		1.0

excepting Gr, tended to set the pure tone at frequencies one, two, and three octaves above the fundamental. However, there was little consistency in the results from subject to subject except for the very general tendency towards higher settings for tone B. If the brightness of complex tones were an attribute similar to the brightness of pure tones (supposedly parallel to that of pitch), there should have been a greater similarity of results among the subjects, and the scatter shown in the settings of each subject except Eg should not have occurred. Furthermore, the judgments could hardly be described as immediately given. The subjects typically took about an hour to make 25 judgments, of which perhaps half the time was given to measuring the frequency of the settings. It seems, therefore, that the brightness of complex tones is not similar to the pitch-brightness of pure tones.

V. Discussion

In considering these results, the first question to arise concerns the meaning and importance of the dimension of brightness, as defined by the D–B series. Several factors suggest that this is an important dimension of tone quality. During the experiment it was evident that the judgments of brightness could be made without great difficulty on the part of the subjects. It was not hard for them to attach the terms bright and dull to the extreme tones of the series and to make judgments on the basis of the given criterion. It will be recalled that the duration of the tones was only two seconds. The ease of judgment appears more important when it is noted that the stimulus difference between successive tones in the series was not large and that in the final scaling no tone was paired with any other more than two steps removed from it in the series. Another factor is the relatively great magnitude of the D–B scale, showing that the extremes were markedly different. This evidence tends to support the subjective impression that there was a fundamental type of change in this series.

The possible generality of the brightness dimension is indicated by the fact that three other series, based on somewhat different types of stimulus change, showed systematic differences in brightness, according to the meaning given to that term by the D–B series. One of these series changed gradually from a tone with the physical characteristics of a sustained vowel 'oh' to one with the physical characteristics of a sustained 'ah,' as these were determined by Lewis and Tuthill (7). In addition to the vocalic change present, listeners reported a change in brightness, as defined by the D–B series. It is possible that brightness may be related to vocality in an important way.

The D–B series and those mentioned in the preceding paragraph as showing a similar change in brightness had one thing in common. Their spectra show that, in successive tones, the median point of the energy distribution was shifted upward along the frequency continuum. This suggests that brightness is a function of the location on the frequency continuum of the midpoint of the energy distribution. If this were the entire cause of brightness changes, the way in which the energy was distributed around the midpoint would have no effect on brightness. The V–P series was originally devised in an effort to determine whether changes in the concentration of energy would cause brightness differences. A study of the spectra of the V–P tones will show that throughout the series the midpoint of the energy in the tone was at the same point on the frequency continuum. The change was in the manner of distribution of the energy around

the midpoint (see Fig. 3). Thus the relations, in experience, between the V–P and D–B series are of theoretical importance. As has been mentioned, the type of qualitative change in the V–P series seemed much like that in the D–B series, although the two series were easily distinguishable.

One method of showing the relations between the two series has been used in Fig. 6. The abscissa represents brightness scale values

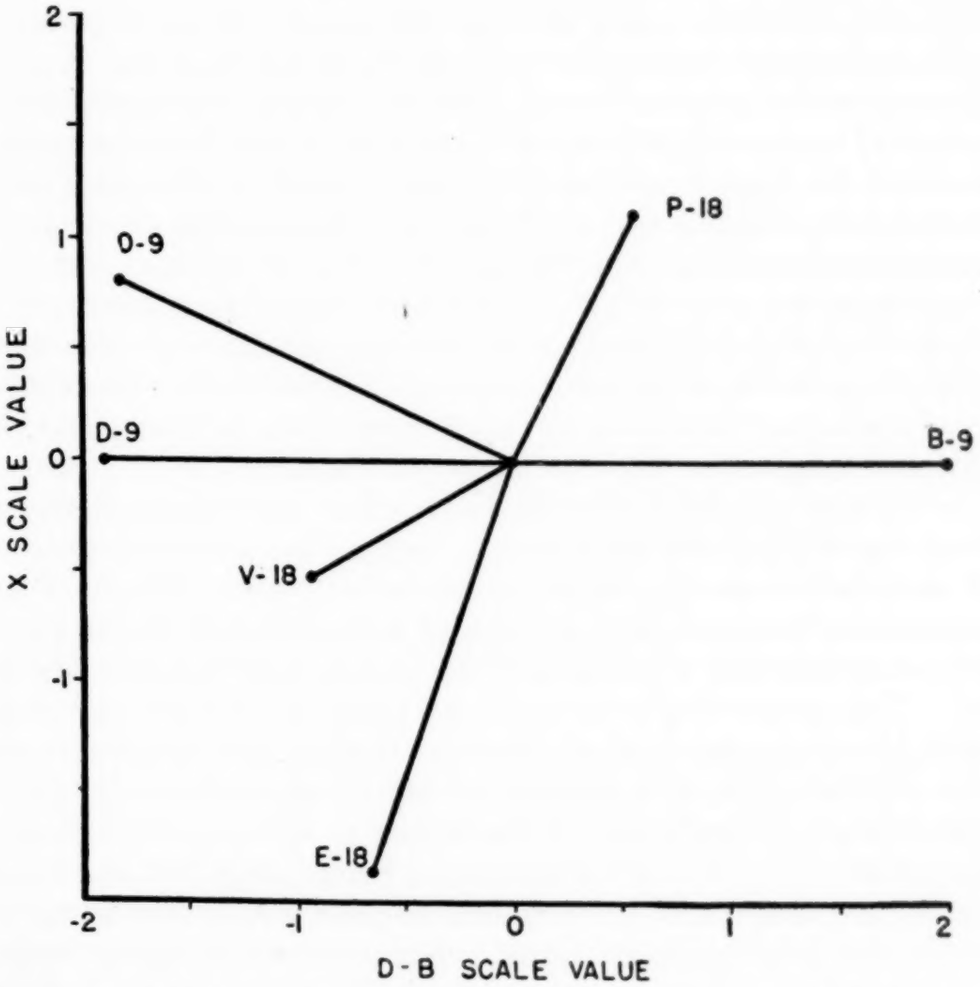

FIG. 6. Certain relations of the V–P and E–O series to the D–B series. The horizontal line represents part of the D–B scale. The scale values of points on this line are given by reference to the abscissa. Each point on the other curves indicates two facts about the tone it represents. Reference to the ordinate gives the scale value of that tone in its own series. Reference to the abscissa gives its brightness value in terms of the D–B scale. Tone B–O, represented by the point at which the curves intersect, is taken as the zero point for each scale.

as determined from the D–B series. The ordinate represents values in either the V–P or E–O scales. Tone B–O is the reference (zero) point for the scales on the ordinate and on the abscissa. The horizontal line in the figure represents a portion of the D–B scale. Each point on this line stands for a tone in the D–B series and shows, by reference to the abscissa, the scale value of that tone in the series.

Each point on the other curves indicates two values for the tone it represents. Reference to the ordinate gives the scale value of that tone in its own series. Reference to the abscissa shows the brightness value of that tone, as brightness was defined by the D–B series. The method by which this was determined has been described. To take an example, the point for V–18 shows that its scale value in the V–P series was −.51 and that it has a brightness scale value of −.94.

The possible meanings of the curves in Fig. 6 may be made clearer if certain hypothetical cases are first discussed. If an X series were independent of the brightness scale in the sense that the X quality could vary while brightness was held invariable, the curve for that series would be a vertical line. If each tone in the X series had equal scale values for both brightness and the X quality, the point for any tone would be equally distant from the central zero point in both horizontal and vertical directions. A series of such points would make a line with a slope of 45°. This curve might possibly mean that the X quality and brightness were entirely separate attributes, and that the tones in the series just happened to possess the two attributes in equal amounts. It would be much more likely to mean that the X quality and brightness were the same attribute.

The curves for the V–P and E–O series pass through the B–O point of the D–B scale because all the series contained that tone, which may be taken as a common reference point. The V–P curve approximates, very roughly, a slope of 45°, although the upper half deviates towards the vertical and the lower half towards the horizontal. The error of the location of these points on the scale is probably great enough so that the exact slope of the line is not meaningful. If the slope is accepted as being approximately 45°, the phenomenological similarity of the scales is not proved. It is still possible that the V–P scale might have been judged on the basis of a separate attribute which happened to give nearly the same scale values as the brightness attribute. Because this is rather improbable, some relation between the two scales seems to be indicated. Brightness, as defined by the D–B series, was probably an important factor in the scaling of the V–P series. If true, this supports the conclusions based on subjective impressions. The possibility that each series had two (or more) attributes and that there was an attribute common to both which caused the relations shown in Fig. 6 will be considered later.

The E–O series may now be discussed. Ever since the time of Helmholtz, psychologists have been pointing out the fact that a tone consisting only of odd-numbered partials has a peculiarly individual quality, resembling that of the low notes of the clarinet. The extreme O tone of the series had this individual quality. That E–18

tended to sound like two tones, one an octave above the other, has been mentioned.

The relations of the E–O series to the D–B series are also shown in Fig. 6. The two halves of the curve almost form a right angle. This might be interpreted as meaning that the two halves of the series were characterized by two different attributes. It might also be taken to mean that the series was judged on the basis of an attribute entirely independent of brightness, but that a brightness factor, increasing from both ends of the series towards the middle, was also present. In Fig. 6, a line drawn directly from the point for V–18 to that for P–18 would approach the vertical. A vertical line, it has been stated, would indicate an attribute independent of brightness. It is possible that the brightness factor was of little importance in determining scale values in this series. The thin-full scale shows no characteristics which are explained by the brightness changes in the E–O series. A hypothesis which accounts for the brightness increase from the ends of this series towards the middle will be given later. The greater brightness of the E tone over the O tone was probably due to the previously mentioned 'split' into two tones. One effect of this octave tone was evidently to add brightness or something confused with brightness. These brightness changes may have been extraneous factors and probably the series was judged primarily in terms of an attribute independent of brightness. Because the E and O tones were less bright than B–O, another attribute must have operated to produce the rank order E, B–O, O in the scale for the E–O series.

A certain analogy will show what the basis may have been for the judgments of the tones in the E–O series. A study of the interval relations (in terms of the musical scale) between the partials in each type of tone will show some interesting differences. In a tone consisting only of the fundamental and the even-numbered partials, up to and including the sixteenth, nearly all of these intervals between partials are octaves, fifths, fourths, major thirds, or minor thirds. Such musical intervals are all very smooth or consonant, and some of them are thin or empty-sounding. In a tone consisting only of the odd-numbered partials, through the fifteenth, the intervals between the partials include a major sixth, diminished and augmented fifths, major and minor thirds, major seconds, and minor sevenths. These intervals are either the fuller-sounding consonances (those last to be accepted as consonances in the development of music) or the dissonances. The same type of difference between the two tones can be shown for the intervals between the fundamental and the higher partials. One type of tone contains many intervals commonly considered to sound thin and smooth; the other contains many intervals

usually considered to be full or dissonant. The effects of intervals of given kinds may be somewhat similar, whether they are between partials or between tones. Such an analysis suggests a possible basis for the original selection (as a result of introspective study) of the terms 'thin' and 'full' to describe these tones.

If developed further, the analogy with musical intervals suggests a possible new factor or attribute in complex tones, namely that of *roughness* or harshness. Helmholtz (**4**) noted that when strong partials above the seventh were present in a tone its quality was likely to be cutting or rough, and he ascribed this quality to dissonances between partials. It should be pointed out that any two consecutive partials above the sixth (seventh and eighth or above) form a dissonant interval of a second. The seventh and eighth partials make an interval of a major second. Consecutive partials higher and higher in the series form smaller and smaller seconds; the interval between partials 15 and 16 is a minor second. Because major and minor seconds are among the most dissonant of the musical intervals, it is conceivable that any two consecutive partials above the sixth might add an element of roughness to the tone. On this assumption, and on the basis of preliminary work, a series was constructed in an attempt to demonstrate roughness. Each tone in the series contained the first six partials and two partials above the sixth. The intensities of partials 2, 3, 4, 5, and 6 were, respectively, 4, 8, 12, 16, and 20 db below that of the fundamental. The intensity of each of the two partials above the sixth was always 10 db below that of the fundamental. In the first tone of the series, the two high partials were the 7th and 8th, in the second they were the 8th and 9th, in the third the 9th and 10th, and so on; those in the last tone of the series were the 15th and 16th.

Twenty-five graduate students in music and psychology served as observers in a study of the roughness series. They made introspective analyses of the series before the possible nature of the tones was discussed and also after the experimenter had defined dullness-brightness and smoothness-roughness. Dullness and brightness were defined with two tones. Each of these contained all of the first 10 partials except the seventh and ninth. Applying previous terminology, one of these tones had a D–10 spectrum, the other had a B–10 spectrum. In other words, in one tone the tenth partial was 10 db less intense than the fundamental; in the other, the fundamental was 10 db less intense than the tenth partial. These tones did not contain consecutive partials above the sixth; therefore roughness, if it existed, should have been present only in very small amounts. Brightness was thus defined entirely in relation to the frequency of the median of the energy distribution. The D–10 tone was also used

to define smoothness. The same tone with an inharmonic partial inserted was used to define roughness.

The data obtained were in the form of written answers to specific questions. To summarize the results: Before hearing any defining tones or verbal definitions, three observers reported that there was an element of roughness present which increased throughout the series. Nine others reported a change towards a less pleasing, more pointed, or more nasal quality. After hearing the terms and the defining tones, 86 percent stated that there was an element of roughness which increased throughout the series. Sixty-seven percent indicated that roughness and brightness were distinguishable attributes. It seems possible to assume, on the basis of this evidence, that roughness may be a basic attribute of complex tones. If so, it is a function of the presence of consecutive high partials in the tone and of their position in the sequence of partials. (The higher the partial numbers of the two consecutive partials, the greater the roughness of the tone.)

If it is assumed that roughness is a basic attribute of complex tones and is a function of the stimulus conditions stated above, the interrelations of the three series can be explained. It must first be recognized that the D–B series changed in brightness and in roughness. The latter change was due to the fact that consecutive high partials became increasingly prominent from the D to the B end of the series. In the following discussion, it must be kept clearly in mind that the term brightness will be used in a new sense to refer only to that quality which is a function of the frequency of the midpoint of the energy in the tone. It is best defined by the D–10 and B–10 tones containing only partials 1, 2, 3, 4, 5, 6, 8, and 10. 'Brightness as defined by the D–B series' means a combination of brightness (in the restricted sense) and roughness.

The probable explanation for the form of the E–O curve in Fig. 6 can now be given. The relations between the E–O and D–B series seem to have been due in part to the presence of an element of roughness in each. On the basis of the present assumptions, it can be said that the extreme E tone and the extreme O tone had little roughness (because the effects of consecutive high partials were minimized as a result of the low intensity of alternate partials) and that the B–O tone had considerable roughness (due to the presence of consecutive high partials). Because the D–B series contained a roughness element which increased toward the B end, the brightness (as defined by the D–B series) of the B–O tone would be much greater than that of the E and O tones. This would give rise to the relation shown in Fig. 6.

To speculate further, possibly all the tones in the E–O series had approximately the same brightness, in the new sense of the term, because the midpoint of energy was at the same frequency in all tones.

The present E–O series might therefore be used to demonstrate that thinness-fullness is independent of brightness. In other words, a new Fig. 6 (based on a revised D–B series) might show a vertical line for the E–O scale. A different type of E–O series, not containing consecutive high partials, might then be devised to show that fullness is independent of roughness.

The attribute of roughness was probably the factor relating the D–B and V–P series. A study of the V–P tones shows that the strength of consecutive high partials, in relation to the level of the fundamental, increased throughout the series. Thus it is probable that the V–P series, like the D–B series, increased in roughness. The result was that the tones of the V–P series showed a similarity to those of the D–B series in terms of the characteristics of the latter. This gave rise to the relations shown in Fig. 6. Perhaps the phenomenological similarities between the two series were caused by the similar roughness changes while the differences were caused by the fact that brightness, in the restricted sense, increased in the D–B series and remained constant throughout the V–P series. The same factors may explain why the magnitude of the D–B scale was much greater than that of the V–P scale. The D–B series changed in two attributes while the V–P series changed only in one.

The possibility of a relationship between the attributes of roughness and fullness needs to be considered. On logical grounds, it is possible to conceive the two as forming a single dimension changing from thin through full (both being relatively smooth) to rough. This dimension would be considered a function of the decreasing simplicity of the frequency ratios (musical intervals) between the partials. According to this view, there could be a continuous and gradual change in this one large dimension from the extreme E tone to the extreme tone of the roughness series. On the other hand, it might be argued that the two attributes are not related psychologically and that to consider them as a single dimension is to commit a stimulus error. Further study of the nature of these attributes is necessary before this point can be decided, but careful introspective analysis seems to indicate that the two attributes are entirely different.

This viewpoint is not inconsistent with the statement that these attributes are different functions of the same variable. Fullness is a function of the relative strength of odd-numbered partials. Roughness is due to the presence of consecutive high partials and is a function of their position in the partial sequence. Both of these stimulus variables can be stated in a more basic way: increasing complexity of the frequency ratios (musical intervals) between the partials in a tone. Assuming something which is perhaps impossible, an index of this complexity of ratios, fullness could be conceived as growing

rapidly to a certain index value (perhaps that at which the interval of a major second is introduced) and very slowly thereafter. Roughness, on the other hand, could be thought of as growing very slowly up to the same value, and growing rapidly as complexity increased beyond that point. Such a conception is based in part on speculative extrapolation of the data, but it is not contradicted by any experimental facts or introspective observations. If the functions were of this nature, the application of Boring's criteria would still show the attributes to be separate.

It may be of interest to note that the qualitative change in the D–B series might be interpreted as being a change in volume or density. Superficially at least, the series seemed to increase in density and decrease in volume from the D to the B end. Since high-frequency partials became increasingly prominent in the series and because raising the frequency of pure tones increases their density and decreases their volume (**9**, **10**), a comparable change may have occurred in the D–B series. Whether volume and density will in the future be shown to be basic attributes of complex tones is problematical.

The B–O tone did not have a very pleasing quality. The tones became progressively more pleasant and musically acceptable toward the D end of the D–B series. Those at the B end of the series were usually considered unpleasant.

VI. Conclusions

The data from the experiment on pitch matching showed that the judgments on which the scales were based did not result from differences in pitch among the complex tones.

The evidence seems to warrant the conclusion that complex tones have, in addition to pitch and loudness, at least three attributes. These are *brightness*, *roughness*, and one tentatively labelled *fullness*. The first two are probably more basic than the third. *Brightness* is a function of the location on the frequency continuum of the midpoint of the energy distribution. The results of the quality-matching experiment suggest that the attribute of brightness in complex tones is not similar to the attribute of pitch-brightness in pure tones. *Roughness* has been shown to be present in tones containing consecutive high partials above the sixth and to be a function of the location of such partials in the whole sequence of higher partials. *Fullness* has been shown to be a function of the relative presence of odd- and even-numbered partials. It has been suggested that roughness and fullness may be different functions of one variable: complexity of frequency ratios between partials.

The question may be asked: Are these attributes necessary to complex tones? According to the present viewpoint, they are to be found in any complex tone. If a tone contains partials above the first, the midpoint of energy is above the fundamental, and some complexity of frequency ratios is present. Therefore, some amount of each of these attributes will be heard. The brightness, roughness, or fullness of any complex tone can be reduced by changing its structure. If any one of these attributes is reduced to zero, the sound must be heard as a pure tone.

It is not suggested that the number of attributes is limited to three. There may be other attributes as basic as brightness and roughness, as well as others of a more restricted nature. The three attributes put forward here may not be sufficient to characterize completely important types of variation in timbre. For example, the series of tones imitating the physical characteristics of the sustained vowels 'oh' and 'ah' were described by introspective report as changing in both brightness and roughness. But to say that this series could be adequately described in these terms would be to go considerably beyond the evidence. It is believed, however, that the three attributes will be found to characterize the main features of many types of qualitative variation in complex tones, and that further study will refine their definitions and show more clearly their importance to auditory theory.

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INTENSITY OF CONDITIONED STIMULUS AND RATE OF CONDITIONING *

BY LAUNOR F. CARTER

Introduction

The purpose of this experiment was to investigate the relationship between the intensity of the conditioned stimulus and the rate of conditioning. Although there are at present 'no precise quantitative laws of conditioning' (**5**) some notable attempts have been made in that direction. In particular, the work of Wolfle (**13**, **14**) and of Bernstein (**2**) should be mentioned. Both experimenters have attempted to express in quantitative form the relationship between rate of conditioning and the time interval between conditioned and unconditioned stimuli. As a result of their studies, we know there is a double sloping gradient in the amount of conditioning as the time interval between the conditioned and unconditioned stimulus is varied.

The problem of the relationship of intensity of conditioned stimulus and the rate of conditioning is closely related to the problem of intensity of conditioned stimulus and amplitude of conditioned response. Hilgard and Marquis (**5**, p. 142) pointed out that after conditioning has taken place, an intense stimulus is more likely to call out a conditioned response of large magnitude than a weak stimulus. The study of Kupalov, Lyman and Lukov (**8**) is commonly cited as showing that after conditioning has taken place, a more intense stimulus will call out a response of greater amplitude than will a weak stimulus. This conclusion, however, should be viewed with considerable skepticism as the experimenters were able to produce this result in only one dog at one time. In other trials with other dogs and with this same dog at other times, this result was not obtained. However, the experiments of Kupalov and Gantt (**7**) and of Newhall and R. R. Sears (**10**) lend experimental support to the point of view that more intense stimuli call out larger responses after conditioning has taken place.

In regard to the relationship between the intensity of the conditioned stimulus and the rate of conditioning, there is some slight evidence that an intense conditioned stimulus does not lead to more rapid conditioning than does a weak conditioned stimulus. Hilgard and Marquis (**5**, p. 142) have investigated data collected by Hovland in connection with the problem of generalization. Hovland used

* From the Psychological Laboratory of Princeton University.

the galvanic skin response and a tone (also a vibrator) as his variables in the investigation. Hilgard and Marquis conclude that "computation of the original data presented by Hovland demonstrates that there was no reliable superiority of one group over the other. At the present time there is no evidence that strength of conditioning, distinguished from response strength, is a function of the intensity of the conditioned stimulus." It is true that Baker (1) has contended that 'subliminal' stimuli, when used as conditioned stimuli, lead to faster conditioning than do supraliminal stimuli; but the work of Wedell, Taylor and Skolnick (12) and that of Hilgard and Ohlson (4) make Baker's conclusions open to serious question.

In order to investigate the effect of degrees of intensity on rate of conditioning, the eyelid response of seven groups of subjects was conditioned to a tone, the intensity of which varied with each group. The apparatus, designed to meet the conditions of this experiment, will first be described before discussing the procedure.

The Apparatus

The apparatus consisted of four units; one to pick up the eyelid blink, a second to administer the air puff, a third to transmit the response to the screen of a cathode ray oscillograph where its progress could be observed, and a fourth unit to present to the subject a tone which served as the conditioned stimulus.

The eyelid response pick-up and the air puffer are illustrated in the accompanying picture (Fig. 1). As may be seen, the small pick-up unit and air puff tube were securely attached to a head-guard such as is used by hockey players who wear glasses. The essential features of this apparatus are the parts for picking up the change in the position of the lid and the means for puffing the eye with air. This air puffer (*A*) was simply a bent brass tube which was mounted in a ball and socket joint so that its position could be adjusted for proper administration of the air.

The eyelid response pick-up used the principle of the capacitance change between the two plates of a condenser as they moved relative to each other. The pick-up consisted of the following arrangement. A small bamboo rod (*B*) was attached by collodion to the eyelid of the subject as close to the eye lash as possible. The bamboo rod was connected by a swivel bearing, to an aluminum lever arm (*C*). The fulcrum of the lever was at its center. At the other end of the lever an aluminum rod (*D*) was mounted by a swivel bearing, and led to a small aluminum tube which moved up and down inside a piece of glass tubing. On the outside of this glass tubing was a fixed aluminum cylinder (*E*). As the aluminum tube moved up and down inside the glass tube, following the movements of the eyelid, it changed the capacitance between itself and the fixed cylinder on the outside of the glass tube. This pick-up was mounted on a carriage which could be moved toward or away from the eye or up and down, so that it could be adjusted to different locations of the eye, relative to the eye's position with respect to the rest of the head.

The capacitance change was led into a capacitance change amplifier which has been described by Loucks (9). The circuit used was identical with Loucks' except for the substitution of a 57 tube in place of his 6K7. The output of this amplifier was led by shielded cable to a cathode ray oscillograph situated in an adjoining room, where it was possible to observe the progress of the lid change relative to the administration of the tone and the air blast.

A tone of a fixed intensity and frequency was presented to the subject in conjunction with the air blast. The tone was generated by a fixed frequency oscillator of 1024 cycles; the tone was led to an earphone on the right ear of the subject.

The air blast was presented to the subject's eye through the head-gear unit already mentioned. A small flexible rubber tube led into the soundproof room and was attached to the head-gear. This tube was cut off from a large tank, by a solenoid-operated air valve outside the soundproof room. The large tank was fed by an air compression machine and a reducing

valve. The air pressure in the tank could be varied as desired. Water manometers were led from each side of the solenoid valve so that the experimenter could tell the standing pressure in the tank and the maximum pressure in the tube leading to the eye, when the valve was opened to present the unconditioned stimulus.

On the experimenter's bench, which was in a room adjoining the soundproof room, there were relays which enabled the experimenter to present the stimuli at any time desired; there was also a timing device as well as an external sweep circuit for the cathode ray oscillograph. There was, in addition, the cathode ray oscillograph in which the experimenter observed the eyelid response. Likewise, there was a valve to control the air pressure and there were switches so that the tone and air could be separately controlled. The timing circuit and the sweep circuit were both run off the same motor and were completely synchronized. The motor made one complete revolution every two seconds and the spot was thus swept over the face of the oscilloscope screen in a period of two seconds. The sweep was a center-tapped 100,000 ohm potentiometer across which was bled 225 v. D.C. The timer was a wiping contact timer on the same

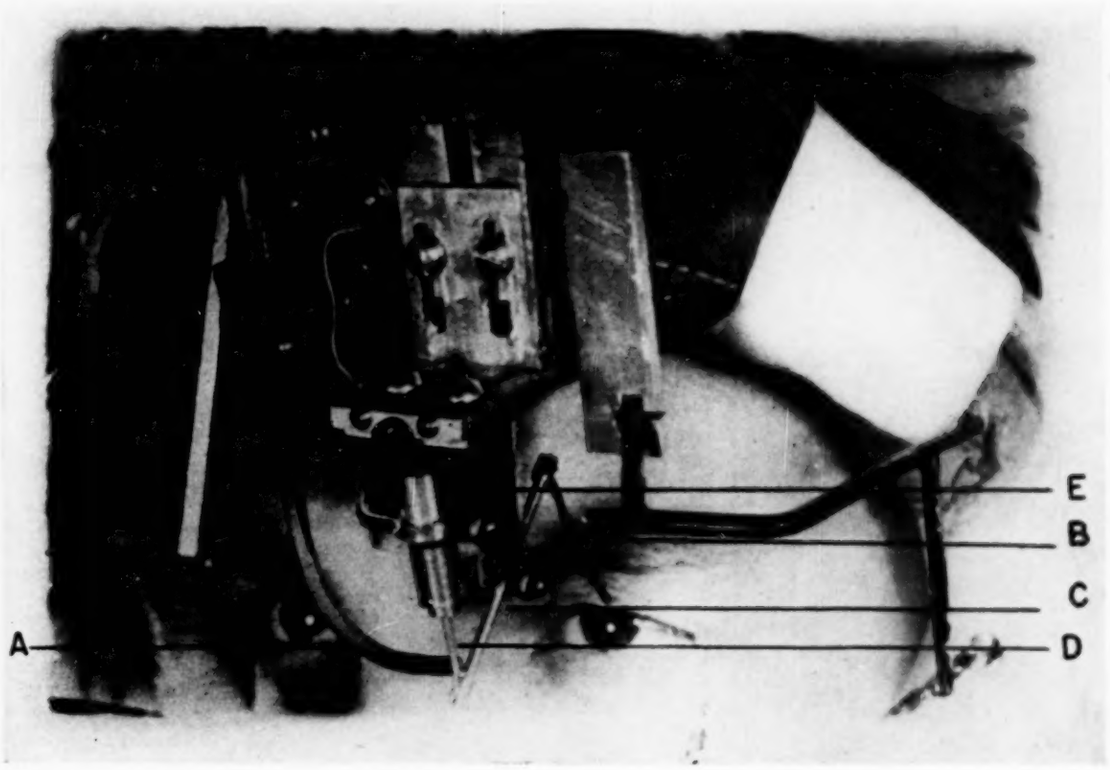

FIG. 1. Unit for administering unconditioned stimulus and picking up response.

shaft as the sweep potentiometer. For every two seconds, the tone was on for .76 seconds and the air was on for .08 seconds. The onset of the tone was adjusted so that it coincided with the appearance of the spot on the extreme left hand edge of the cathode ray tube. The tone relay which completed the plate circuit of the oscillator was automatically closed by the timer as the spot took up this left hand position. At the end of .76 seconds this relay was released and the air relay closed for .08 seconds at the end of which period it was released. During the remaining part of the sweep, no stimuli were presented. A third relay was employed so that the spot would be bright only during the sweep cycle in which stimuli were presented. The following wiring diagram represents the circuits on the experimenter's bench (Fig. 2).

The apparatus as here described has a number of advantages over the conventional apparatus used to measure eyelid responses. Usually with the photographic, pneumographic, or string-lever techniques, the subject's head must be held in a fixed and somewhat uncomfortable position. In the apparatus used in this experiment, the subject's movements were restricted only to the extent imposed by the leads to the apparatus. Thus, the subject could assume almost any

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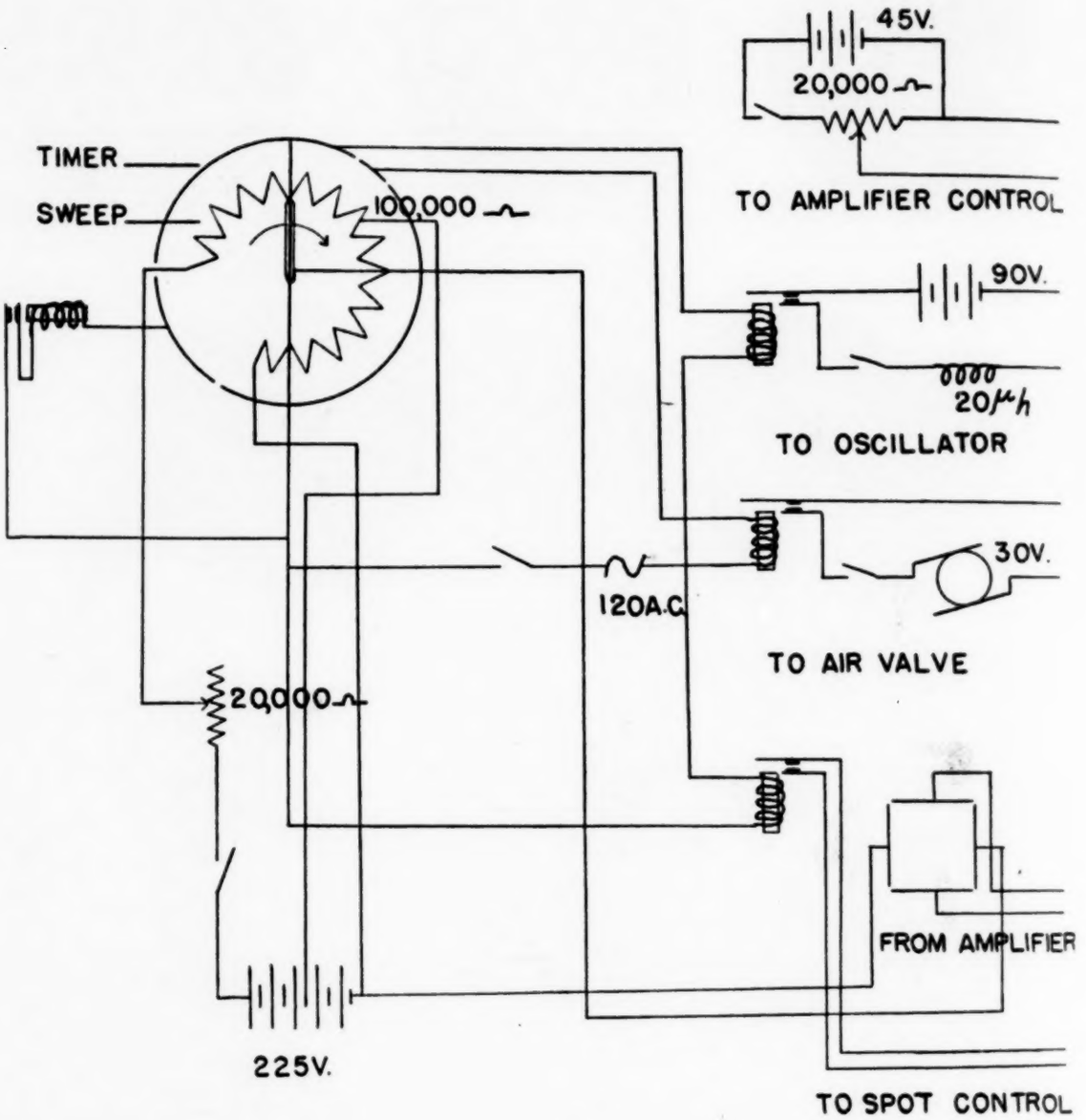

FIG. 2

position or make any shift of position he desired. Furthermore, the part of the apparatus which the subject supported was no more annoying than the wearing of any head-gear.

Another distinct advantage of this apparatus is the fact that it is entirely unnecessary to take photographic or other permanent records. A slow-fading cathode ray oscillograph tube was used in the experiment and it was perfectly possible to observe each response fully half a minute before it faded from view.[1] Thus, after the apparatus is built, there is no further expense involved in its operation, and likewise there is no extra work such as is necessitated in developing and analyzing pictures. In Fig. 3 may be seen the type of responses observed on the face of the cathode ray oscillograph.

[1] This slow-fading feature, however, was not essential as it was very easy to tell the kind of response that was taking place as one watched it formed from moment to moment as the spot moved across the tube. Although no measurements of magnitude of response were made in this experiment, such measurements could easily have been made with an ordinary tube.

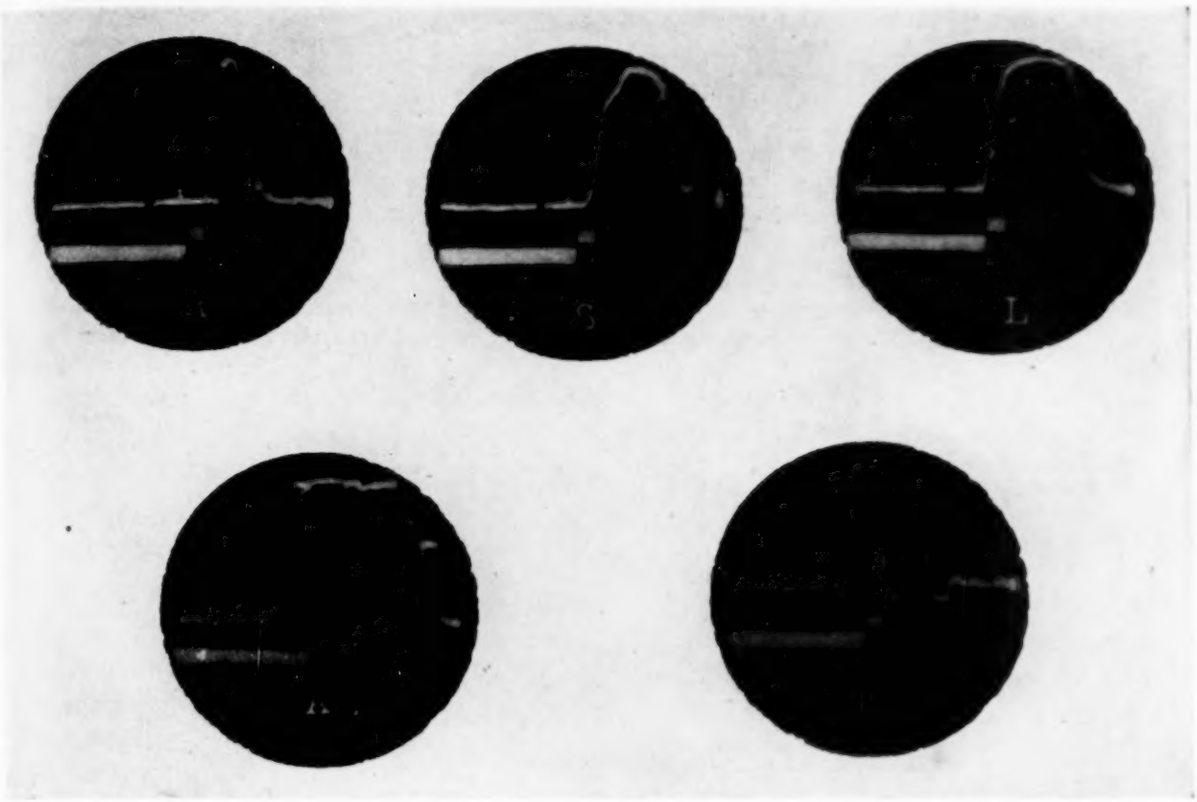

FIG. 3. Eyelid responses. Top line, eyelid response; second line, unconditioned stimulus (air puff); bottom line, conditioned stimulus (tone). See text for discussion of different types of responses.

Finally, it should be mentioned that the apparatus is extremely stable and reliable. In only one case did it break down in running more than 70 subjects, and that was due to the clumsiness of the experimenter.

THE PROCEDURE

The subject [2] was placed in a soundproof room where the experiment was conducted. First, his threshold of hearing was quickly determined. The procedure was to test the subject with a Western Electric 2–A Audiometer at 1024 cycles by the method of limits, with three trials in each direction. The average of the six measures was taken as the subject's threshold for the tested ear at 1024 cycles. The head-gear was then placed on the subject and the bamboo rod attached to the eyelid. The apparatus was properly adjusted for the individual's eye and the earphone was placed over the subject's tested ear. The subject was given a sheet of typewritten instructions and the experimenter left the soundproof room. There was no noise other than the tone of the conditioned stimulus in the soundproof room at any time. The subject was told in the instructions that this was an experiment in measuring eye potentials and that he should let his eyes and eyelids do whatever they wanted to do, but to keep his field of vision above a line on the wall. This instruction tended to keep the eyelids from drooping. He was also instructed to try to keep awake, as one of the subjects in some preliminary experimentation had actually fallen asleep while the stimuli were being administered.

When the experimenter left the soundproof room, he entered an adjoining room where the timing, stimulating, and recording apparatus was situated. The stimulating procedure was as follows:

1. The response to tone alone was tested five times.
2. The response to air alone was tested twice.

[2] The subjects were volunteers from the introductory course in psychology of Princeton University.

3. The response to tone alone was tested twice.
4. 50 paired presentations of the tone and the air were given. These presentations were separated by from 16 to 28 seconds.
5. The tone was presented 10 times alone in an extinction series.

This complete procedure, from the time the subject entered the soundproof room to the time he left, took about forty minutes.

Seventy subjects were used in the experiment. Ten of these subjects, acting as a control group, received no tone whatsoever in Step 4 above; in other words, they were treated exactly like the other subjects in all steps but Step 4 when they simply were puffed in the eye 50 times. The remaining subjects were divided into six groups of 10 subjects each. Each group was conditioned at one of the following intensities of tone: 15, 30, 45, 60, 75, and 90 db. above threshold. The unconditioned stimulus was a puff of air which was obtained by opening the air valve .08 seconds on a standing air pressure of 15 centimeters of water; this built up to a maximum of 5 centimeters of water in the air stimulus line.

The Results

The stimuli were administered by the experimenter, and at the same time he observed any response of the eyelid by means of the movement of the spot on the face of the cathode ray oscillograph. The experimenter, while observing the response, classified it into one of the five types listed below. The types are illustrated in Fig. 3.

R for a reflex response to the air puff,
S for an anticipatory conditioned response of small magnitude running into the reflex response to the air,
L for an anticipatory conditioned response of large magnitude running into the reflex response to the air,
A for an anticipatory conditioned response of great magnitude reaching a maximum amplitude before the reflex to air, and
T for an anticipatory conditioned response reaching a maximum and returning to the base line before the response to the air.

These same notations were used for all steps of the experiment even though, in steps other than Step 4, one of the stimulus components might be lacking.

It should be noted that the pictures here presented represent a selection from a large number of negatives. The pictures should not be thought of as representing the only types of response found; indeed, responses of almost every form and time characteristic were observed and would represent an infinite number of gradations between the types pictured. Descriptions of the conditioned eyelid response which have previously appeared in the literature give the impression that the response is a uniform, continuous change, but actually this does not seem to be true of the majority of the subjects.

As may be seen in Fig. 3, there were time lines on the face of the cathode ray oscillograph. Any response was counted an anticipatory conditioned response and classified by the above system if it appeared between the onset of the tone and the turning off of the air.

Whatever limits are set as signifying a conditioned response are bound to be rather arbitrary, and the limits chosen represent a definite interval of time against which it is easy to measure the response. The limit of the turning off of the air was chosen because in no subject was the reflex to the air observed to occur before this point. In the results, all responses of type *S*, *L*, *T*, or *A* are lumped together under anticipatory conditioned responses as the individual types did not show any trend not reflected in the total anticipatory conditioned responses. The percentage of the different types making up this total for all the subjects is: *T*, 30 percent; *S*, 23 percent; *L*, 13 percent; and *A*, 34 percent. Table I presents the results of this experiment.

TABLE I

AVERAGE NUMBER OF RESPONSES BY THE 10 SUBJECTS OF EACH GROUP

db Intensity	Threshold	R to 1st Test	R to 2nd Test	Anticipatory CR	Extinction R	Total CR
No Tone	−0.8	.2	.4	6.3	1.8	8.1
15	−0.5	.2	.5	24.3	2.3	26.6
30	+0.9	.2	.6	25.5	4.6	30.1
45	+1.5	.0	.0	25.7	4.4	30.1
60	+1.4	.3	.5	23.6	2.5	26.1
75	−1.0	.4	.4	23.5	4.2	27.7
90	+0.8	1.1	.7	30.1	5.2	35.3

Each figure is the average of 10 cases. The column headed db intensity represents the intensity of the tone used as a conditioned stimulus for the ten members of each group. 'Threshold' is the average threshold of the subjects, and a minus sign indicates that the hearing was more acute than the normal. 'R to 1st test' indicates the average number of responses to the tone alone as it was presented in Step 1 of the procedure. 'R to 2nd test' is the average number of responses to air alone in Step 3. 'Anticipatory CR' is the average number of anticipatory responses for the 50 conditioning trials of Step 4; and 'Extinction R' is the average number of conditioned responses given during the 10 extinction trials of Step 5. 'Total CR' represents the average total number of conditioned responses given during the paired presentations and the extinction trials.

The group which received no tone show that there are a certain number of responses which would be called anticipatory conditioned responses in the other groups, but are actually spontaneous blinks or conditioned responses to some uncontrolled signal. The author believes that there were no uncontrolled signals, but such may have existed. Under any circumstances, the number of responses counted as anticipatory conditioned responses in the groups receiving the

pairing is so much greater than that of the group receiving the air puff alone that there can be no doubt that conditioning occurred. An F test for the significance of the difference gives a value of 242 between these two groups. On entering a table of F with 1 and 68 degrees of freedom, it can be seen that this is far beyond the 1 percent limit of confidence.

By inspecting either the anticipatory conditioned response column, the extinction series column, or the total conditioned response column, it may be seen that in no case is there a consistent trend. That is to say, there is no apparent relationship between the intensity of a conditioned stimulus and the rate of forming a conditioned response. An F test yields the following values for the different groups. The F test for the difference between the group means for the anticipatory conditioned responses is .39; for the extinction series, it is 1.89; and for the total number of conditioned responses, it is .58. It can be seen by entering the table of F with the appropriate degrees of freedom that all these group means could have been drawn from the same population.[3]

Discussion

The results of the present investigation seem to be contrary to the theoretical expectation of both Holt (**6**) and Pavlov (**11**). On the other hand, they are in direct agreement with the contentions of Guthrie (**3**).

Holt uses, as the fundamental mechanism accounting for learning, the concept of neurobiotaxis. Using this concept, Holt speaks of the 'canalization' of a response. Thus he says (p. 214), "Such pathways will present at synapses somewhat less resistance to the nerve impulse, so that deep canalization probably favours reflex response much as intensity of sensory stimulation favours it." As these reflexes are conditioned reflexes for Holt, this experiment would appear to be contrary to the above contention. Holt argues that intensity is represented by the frequency of all-or-none pulsations in a given nerve fiber. Since canalization is a result of neurobiotaxis, and as conditioning is a special case of neurobiotaxis, it follows that a higher frequency would cause deeper canalization and hence an increased rate of conditioning and resistance to extinction. Inasmuch as Holt's theory is dependent on this type of argument, the present experiment does not support the theory.

[3] It is of interest to note that an F test between all seven groups on the extinction series shows a value of 3.27 which, with the appropriate degrees of freedom, is less than the value needed for 5 percent limit of confidence. If, then, we think the extinction series is indicative of conditioning, we must conclude that pseudoconditioning took place in the group which received only the air puff. Although the number of responses in this group is the smallest of any group in the extinction series, it could well have been drawn from the same population as the means of the other groups.

Pavlov (11) also argues that increased intensity of stimulus causes more rapid conditioning. Increased intensity of stimulus sets up a greater excitation area on the cortex which leads to closer connection between this center and the unconditioned stimulus center to which it must be connected. Indeed, Pavlov says in discussing generalization (p. 186), "These reflexes decrease progressively in strength with increasing distance of the secondarily excited areas from the point of primary cortical excitation, since the magnitude of the conditioned reflex is rigidly determined by the intensity of excitation." If Pavlov refers here to the conditioned stimulus, as presumably he does, then the present study is in agreement with the many others which tend to throw doubt on Pavlov's theory of cortical function.

Guthrie (3, p. 94–95, 103–113) discusses the place of intensity in learning or conditioning and rejects intensity, as such, as a factor leading to surer or quicker learning. Indeed, Guthrie contends that all conditioning takes place in one trial. The only function of intense stimulation is to produce more cues, both external and internal, which may take on the power of calling out the response. Guthrie would predict that in the present experiment there would be no change in the rate of conditioning as the stimulus became more intense. This would hold until the stimulus became so intense that it called out increased stimulation from other sense modalities. If we grant that a tone of 90 db. above threshold is not likely to add increased differential proprioceptive cues or increased external cues to those already present, the results seem to be in complete accord with Guthrie's theory.

Summary and Conclusions

This experiment was devised to investigate the relationship between the intensity of the conditioned stimulus and rate of conditioning. The eyelid responses of different groups of subjects were conditioned to auditory stimuli varying for the different groups between 15 and 90 db. above threshold. The results show that within the limits of this experiment, there is no change in the rate of conditioning with different intensities of conditioned stimulus.

The results are discussed in the light of the theories of conditioning of Pavlov, Holt, and Guthrie. It is suggested that the results are contrary to the expectations of both Pavlov's and Holt's theories of conditioning; on the other hand, the results seem to be in agreement with the results which would have been predicted by Guthrie.

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FORWARD CONDITIONING, BACKWARD CONDITIONING, PSEUDO-CONDITIONING, AND ADAPTATION TO THE CONDITIONED STIMULUS[1]

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INTRODUCTION

A number of investigators in the field of human conditioning have sought for the most favorable interval between the conditioned and unconditioned stimuli. The temporal gradient in the case of classical conditioning has been investigated by Bernstein (1), and in the case of avoidance conditioning by Wolfle (20, 21), to mention only two of the several studies (3, 4, 5, 15, 13). These investigations have univocally shown that one of the least favorable temporal relationships for conditioning to occur is the so-called backward order of stimuli, namely, a situation in which the conditioned stimulus does not occur until after the termination of the unconditioned stimulus.

The same phenomenon has been established for the rat by Carr and Freeman (2) and by Yarborough (22), for the intact dog by Pavlov (12), and for the spinal dog by Shurrager and Culler (14).

The suggestion might be made that the appearance of so-called backward conditioning may in part be explained in terms other than that temporal relationship of the conditioned and unconditioned stimuli peculiar to backward conditioning. Grether (7) first called attention to this possibility, although Bernstein earlier had suggested that a good number of responses which Switzer (15) termed backward conditioned responses were actually facilitated unconditioned responses to the conditioned stimulus. Grether, with monkeys, obtained responses which were indistinguishable whether he gave the monkeys 10 backward conditioning training trials or training consisting merely of 10 presentations of the unconditioned stimulus. He felt that adequate controls for this 'pseudo-conditioning' should be run before backward conditioning can be said to have occurred, controls which Switzer, Wolfle, and Bernstein failed to take into account. Grether further stated that 'pseudo-conditioned' responses such as he obtained differ in important ways from the facilitated unconditioned responses to the conditioned stimulus which Bernstein had investigated.

[1] This investigation was carried out while the writer was a Research Fellow at the University of Colorado. The writer wishes to thank Drs. D. D. Wickens and L. I. O'Kelly for their generous advice throughout the course of the experiment.

Harlow (8) has demonstrated pseudo-conditioning in the cat, noting that the pseudo-conditioned responses were not as strong as the unconditioned responses to the unconditioned stimulus and were retained not longer than 4 days. He also investigated pseudo-conditioning in the goldfish (9), finding that pseudo-conditioned reflexes were established perhaps more rapidly than forward conditioned reflexes, were quite stable, and were retained 'as long or longer than' true forward conditioned responses. Hilgard and Grant present similar data with human beings (11), which will be discussed in detail later.

That the effects of pseudo-conditioning can be differentially distinguished from those of forward-order conditioning is shown by an experiment of Wickens (17). Using forward time intervals he trained a group of subjects to raise the middle finger from an active electrode upon presentation of a buzzer. After conditioning had occurred, the hand was turned over so that an antagonistic muscle group response was effective in avoiding the shock. Of 18 subjects, 17 avoided the shock upon presentation of the first 4 or more sounds in the second, palm up, situation. This was in sharp contrast to a group given pseudo-conditioning training. Only 2 of 14 subjects, given shock only in the palm down situation, responded to the first sounds in the palm up situation.

This implies that the effects of pseudo-conditioning and the total effect of forward conditioning are dissimilar in certain circumstances, not that pseudo-conditioning training has little or no effect in the human subject. The pseudo-conditioning training in the palm down situation of Wickens had a very definite effect on subsequent forward conditioning in the palm up situation. The difference between number of trials necessary to reach a criterion in the case of the typical forward-order group and in the case of a group given previous pseudo-conditioning training with the antagonistic muscle group is found on an analysis of Wickens' data to be reliably in favor of the latter group (C.R. = 3.88). The fact that the experimental group was trained to respond with one muscle group while the control group was trained with the antagonistic muscle group does not seem important enough to invalidate this comparison, especially since the palm down training of the pseudo-conditioned group would tend to diminish the difference found reliable.

We may say then that explanations of forward as well as of backward conditioning should take the facts of pseudo-conditioning into account.

Still another factor which should be taken into account is that of adaptation to the conditioned stimulus. Bernstein gave each of 2 subjects who had been well conditioned a series of 30 conditioned

stimuli, noting that all responses disappeared in 4 and 10 presentations of the conditioned stimulus, and states that the "data suggest that there is a facilitative effect during the training series that counteracts or delays the rapid disappearance of the response which would occur if the sound were repeatedly presented alone" (p. 184), a conclusion in which Hilgard and Biel (10) concur. It should be carefully noted that this conclusion was applied only to the facilitated unconditioned response to the conditioned stimulus, not to the longer-latency true, or 'beta' conditioned response. The results of Grether and Harlow already cited suggest, however, that this conclusion may be valid for true conditioned responses as well.

The present experiment was designed to provide opportunity for four phenomena to appear distinguishably in groups of human subjects: forward conditioning, backward conditioning, pseudo-conditioning, and adaptation to the conditioned stimulus. An avoidance reaction, finger withdrawal from shock, was conditioned to a loud complex tone.

Apparatus

The apparatus consisted in part of a board 1″ × 6″ × 24″, on which was mounted apparatus for administering shock and for recording the response. The shock system was similar to that used by Wickens (17), while the recording system was adapted from Watson (16). A balloon attached to a small metal cup was inverted over the subject's third finger of the right hand and attached through small rubber tubing to a Marey tambour mounted to write on a kymograph. This system recorded the occurrence and amplitude of upward and downward movements of the finger as small as one-sixteenth inch and as much as two inches.

The conditioned stimulus, the loud tone, was presented through earphones connected to the secondary of a small transformer whose primary was connected to 110 volt a.-c. current. There being no other resistance in the circuit, the sound presented was a 60 cycle tone of an intensity not much short of being painful.

The durations of the conditioned and unconditioned stimuli and the temporal relationship between them were determined by a continuously variable interval timer as described by Wickens (18). This timer also activated a signal magnet every quarter-second. Thus, on a completed kymograph record were obtained the durations and temporal relation of the stimuli, the amplitude and duration of the response, and a time line in quarter-seconds.

The subject sat in a comfortable chair on the arm of which was the conditioning board. Rubber tubing from the balloon on the board and wires for shock and sound led through a hole in the wall to the experimenter's adjacent room containing all other apparatus. There was no door or other opening between the two rooms.

Subjects.—Forty-two students in the elementary psychology class volunteered as subjects. Eighteen of these were women, distributed among the groups as evenly as possible. All of the subjects were acquainted with the essential facts of conditioning.

Procedure

A subject was seated in the chair, his middle finger placed on the active electrode, the indifferent electrode attached to the wrist, and the whole forearm strapped down firmly but not tightly. The shock was then turned on at subliminal strength and gradually increased until the subject signalled that it was as strong as he would take. It was immediately turned off. At that point, watching the recording lever, the experimenter gave an unexpected shock to determine whether a momentary shock of that intensity was sufficient to produce an unconditioned response. If so, the experiment was begun with this shock intensity; but from time to time the intensity was increased slightly in an effort to overcome adaptation to the shock.

The subject was then instructed to take a passive attitude in so far as possible, neither to try to become conditioned nor to fight against it. The lights in the subject's room were then turned off, and the experimenter left the room and locked the door. In the second experimental room the interval timer and kymograph motors were started and the following sequence of stimuli presented to all subjects:

1. 3 sounds, each of $4\frac{3}{4}''$ duration.
2. 3 shocks, each of $\frac{1}{4}''$ duration.
3. 80 training combinations, the type of training varying from group to group as follows:
   a. Forward-order Group received $4\frac{3}{4}''$ of sound followed by $\frac{1}{4}''$ of shock,
   b. Backward-order Group received $\frac{1}{4}''$ of shock followed immediately by $4\frac{3}{4}''$ of sound,
   c. Random-order Group received 80 sounds and 80 shocks just as did the preceding groups, but in a chance order and with as much variation of the temporal interval between adjacent presentations of the stimuli as was possible in one experimental session,
   d. Pseudo-conditioning Group received no sound, but received a series of 80 shocks.
4. 10 sounds, each of $4\frac{3}{4}''$ duration.

Following the extinction series of 10 sounds alone each subject was released and questioned about his reactions during various phases of the experiment, whereupon the session was terminated.

For all groups, the interval between adjacent training combinations was varied at random between 1, 2, 3, or 4 rotations of the interval timer drum, that is, between $5\frac{1}{2}''$, $16''$, $26\frac{1}{2}''$, or $37''$.

Results

1. *The Unconditioned Response to Sound*

Twelve of the 42 subjects made finger responses to the 3 initial sounds, 8 subjects responding only to the first, 3 responding only to 2, and only 1 subject responding to all 3 sounds. No subjects were discarded for this reason. An analysis of the records of the Forward-order Group failed to give any indication that this reflex response was augmented during the 80 forward-order training combinations.

An important difference is found between the Forward-order Group and all other groups with respect to the time of onset of response to sound in the series of 10 extinction trials. When during training the $4\frac{3}{4}''$ of sound is invariably followed by shock, a response to sound alone does not typically appear during the first 2 seconds of shock, but as has been generally noted in avoidance conditioning (6), tends to anticipate the shock in a more efficient manner by appearing just in time to avoid the shock. This tendency is in rather sharp contrast to the behavior of the other groups where, upon presentation of sound in the extinction series, the responses typically occur during the first half-second of sound.

2. *The Unconditioned Response to Shock*

Nothing was to be remarked here in any way different from the numerous other studies using finger withdrawal from shock. The usual wide individual differences appeared in amount of shock tolerated as well as in rate of adaptation. The unconditioned response of one subject was flexion, in contrast to the extension usually found. As downward movements of the finger were recorded as precisely

as upward although the excursion was limited, and as this subject did not exhibit other peculiarities, the record was not discarded.

No difference with respect to the reaction to shock could be found between the Pseudo-conditioning Group, which received no sound during training, and any of the other three groups.

3. *The Pseudo-conditioned Response to Sound*

The results of the Pseudo-conditioning Group are shown in Table I, and are compared with those of the Random-order Group

TABLE I

PERCENT OF RESPONSE

Groups	No. of Subjects	Extinction Trials					
		1	2	3–4	5–6	7–8	9–10
Forward-order	10	90.0	70.0	60.0	35.0	30.0	35.0
Backward-order	13	84.6	46.1	30.7	23.0	26.8	23.0
Random-order	9	44.4	33.3	22.2	16.6	22.2	22.2
Pseudo-conditioning	10	100.0	80.0	30.0	10.0	20.0	10.0

Table I shows the percent of responses made by each group to the extinction series of 10 sounds alone.

in Fig. I. An initial high level of response in this pseudo-conditioned group is to be observed. All subjects responded to the first presentation of sound after 80 shocks, following which trial the strength of response is seen to fall off relatively sharply.

4. *The Conditioned Response to Sound*

The results of the four groups in terms of the percent of possible responses during the extinction series is presented in Table I. It will be noted that all groups show an appreciable stability of response.

A comparison of only those groups which received 80 sounds and 80 shocks during training is afforded in Fig. II.

DISCUSSION

1. *Facilitation vs. Pseudo-conditioning*

In this general experimental situation some movement of the finger to the initial sound is the common finding. Wickens (17) reports 11 out of 32 subjects responded in this fashion. Other than the observation that it usually extinguishes in 1 or 2 trials, the course of this particular unconditioned response to sound has not been investigated.

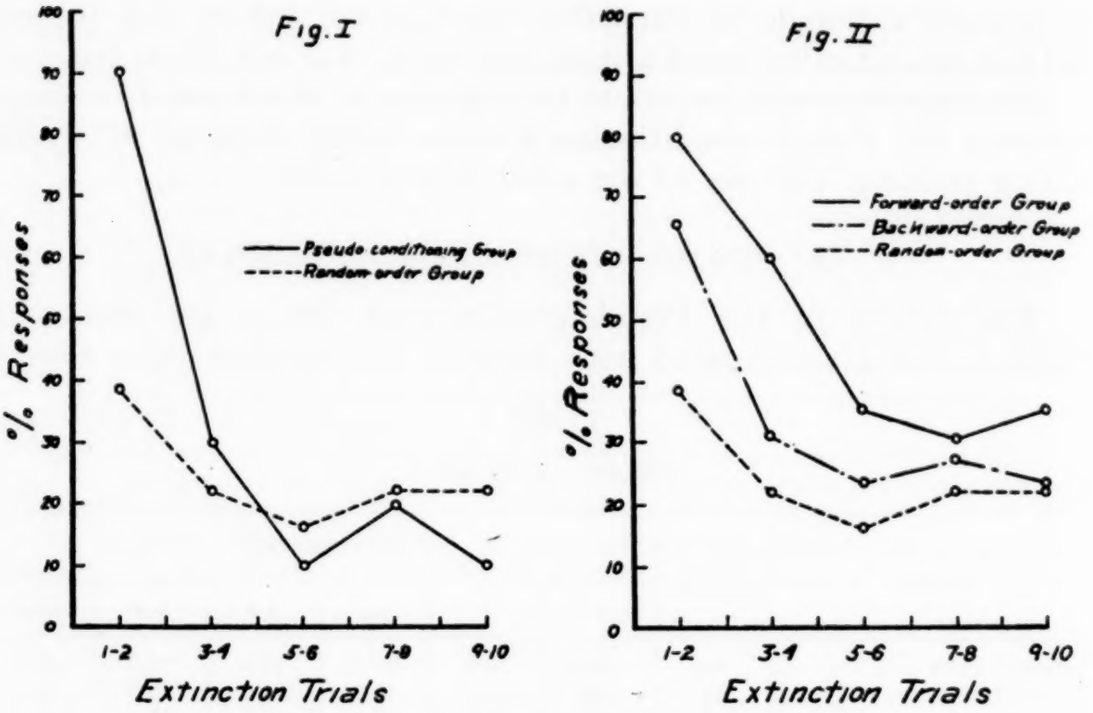

FIG. I. The effect of nonassociative factors. Fig. I, plotted from Table I, compares the decrement in strength of response of the Pseudo-conditioning Group and the Random-order Group.

FIG. II. The effect of temporal relationship. Fig. II, plotted from Table I, compares the decrement in strength of response of those groups receiving the same number and kind of stimuli but with different temporal relationships between the conditioned and unconditioned stimuli.

The results of the present experiment clearly show that it is not facilitated, or sensitized, during forward-order delayed conditioning training. The data do at first glance suggest that this response is facilitated during such training as was given to the other three groups. Since with these groups in the extinction series the time between the onset of the sound and the onset of the response was of the order of the unconditioned response to the three initial sounds, it could be held that the training given these groups merely facilitated this unconditioned response.

Some evidence that this may not be the case is found in Grether's and Harlow's work already cited (where the concept of 'pseudo-conditioning' was felt preferable), and in a control experiment of Bernstein's in which he demonstrated that, while facilitation of the reflex eyelid wink occurs, this facilitation can be shown to occur as well with random-order presentation of stimuli as with the typical forward-order. We should, therefore, if the responses noted were merely facilitated unconditioned responses as Bernstein concludes, expect that they would be elicited after either forward-order or random-order presentation of stimuli. Since in the present experiment the Random-order Group, given training comparable to Bern-

stein's control group, exhibited short-latency responses *while the Forward-order Group did not*, some doubt is cast upon the viewing as facilitated unconditioned responses those responses occurring during extinction of at least the Random-order Group.

A similar argument could be constructed from the results of Hilgard and Grant, taken together with the results of the Pseudo-conditioning Group in the present experiment. These authors found reflex sensitization of the eyelid wink after repeated presentation of the unconditioned stimulus alone. If the results of at least the present Pseudo-conditioning Group are to be explained as reflex sensitization, following Hilgard and Grant, then presumably the reflex sensitization which Bernstein and Hilgard and Biel found in forward-order conditioning should also appear in the present Forward-order Group. We have already noted that this does not occur.

The argument has been that, although reflex sensitization has been observed in groups given training comparable to the Random-order and Pseudo-conditioning Groups, the responses of at least these two groups need not therefore be classed as evidence of reflex sensitization, since in the present experiment no sensitization is found in the Forward-order Group; whereas in the random-order and pseudo-conditioning situations mentioned, where reflex sensitization is found, it is also found under forward-order conditions. This distinction may be more than merely suggestive.

Further evidence that the criterion responses of the Backward-order, Random-order, and Pseudo-conditioning Groups were something other than facilitated unconditioned responses is provided by the protocols of the subjects' statements at the conclusion of each experimental session. Quite commonly the 12 subjects who made finger movements to the initial sounds reported their responses as involving many muscle groups. "I jumped," "The sound startled me," were typical statements. This rather generalized response was not noted by the subjects of these three groups in the case of the extinction series. Here it seems to have been much more confined, involving rather specifically the extensor muscles of the fingers. The concept of pseudo-conditioning appears well suited to explain the fact that these responses were similar rather to the responses to shock than to the responses to the initial sounds. If the responses of these three groups were in truth facilitated unconditioned responses, as seems unlikely, it is certain that at least the form of the response was considerably altered.

2. *Effect of Nonassociative Factors on Stability of Response*

A consideration of Fig. II will show that the stability of response seems partly a function of the temporal relationship between the

stimuli. It is to be especially noted, however, that a considerable degree of stability of response is exhibited even in the Random-order Group, where the extreme temporal irregularity could hardly lead to any appreciable strength of response on the basis of temporal factors alone. It is the response stability of this group which offers the most difficult problems: apparently one must look farther than the facts of the temporal gradient in avoidance conditioning.

Some light on the results of the Random-order Group is thrown by the results of the Pseudo-conditioning Group. The latter group demonstrates that associative factors due to pairing of the conditioned and unconditioned stimuli are not necessary to obtain a certain stability of response. (See Table I.) One might conclude that nonassociative factors may, by supplementing or decrementing associative factors, account in part for the response stability of groups given typical conditioning training. A similar conclusion has been reported by Hilgard and Grant (**11**). If, following these authors, we are to explain in part the results even of forward conditioning in terms of nonassociative factors, it is possible to explain the results of the Random-order Group almost entirely in this way.

In Fig. I are compared the two groups in question. Leaving the manifestly superior initial stability of the Pseudo-conditioning Group unexplained for the moment, it is seen that the two curves are thereafter very similar; the reliability of the difference between the two groups in the last 7 extinction trials is negligible (C.R. = .50). No factor other than the nonassociative one involved in pseudo-conditioning need be advanced to account for at least the latter phases of the Random-order extinction curve.

As for the initial superiority of the Pseudo-conditioning Group over the Random-order Group (C.R. = 2.51, first 3 trials), this is obviously a function of the only difference in the training given these groups, namely, the interspersing of 80 sounds among the 80 shocks in the latter group. As a result of including these sounds in training, this group fails to respond to initial criterion sounds with anything like the strength of the other group.

Since it is undoubtedly these sounds which reduce, either directly or indirectly, the strength of response to subsequent sounds, some concept similar to that of negative adaptation would seem to apply. In response to the initial criterion sounds, then, an adaptation factor would be operating in the case of the Random-order Group but not in the case of the Pseudo-conditioning Group.

(The factor of adaptation to sounds given during *training* is not to be confused with that of adaptation to sounds given during *extinction*. Also, it is not implied that the mechanism of experimental extinction is simply that of negative adaptation.)

One might for convenience envisage the stability of response of the Random-order Group as the biological resultant of two mutually opposed vectors arising during training, that of pseudo-conditioning tending to increase probability of response to criterion sounds and an adaptation factor tending to decrease this probability.

It follows that if these factors largely account for the results of these two groups, one is not able to disregard them and yet explain adequately the results of the Backward-order or of the Forward-order Groups.

It is of course recognized that a great many nonassociative factors *may* be present in human conditioning. Wickens (19), in an inchoate integration of conditioning with the holistic point of view, has pointed out that "attitudes, motivational and drug conditions, other conditioned responses, the degree of integration of the total organism, and perceptual factors—all have an undeniable influence on the quantitative and qualitative nature of the conditioned response." Such factors as these, however, are in one sense incidental, and may be distinguished from relatively constant factors which are inherent in the presentation of the stimuli.

3. *Effect on Stability of Response of Temporal Relationship of Stimuli*

A consideration of Fig. II will show that, as might be expected, the Forward-order Group exhibits the greatest stability of response. Chances are at least 99.5 in 100 that the differences between this group and either of the other groups are true differences.

a. Forward-order as Compared with Random-order Training

The difference between the Forward-order Group and the Random-order Group (C.R. = 3.04, first 5 trials) is obviously the result of a factor not operating appreciably, if at all, in the Random-order Group, namely, the associative factor due to the regular and favorable temporal contiguity of stimuli. Yet this factor, for so long thought of as the only constant factor working to produce conditioned responses, is here shown to be only one, though perhaps the most important one, of at least three [2] factors operating in forward condi-

[2] In this connection it is interesting to note that Hilgard and Grant report a variation of the pseudo-conditioning effect. After testing the reflex wink to sound or to light, instead of administering the usual puff of air to the cornea as in pseudo-conditioning, they had a control group merely sit and fixate during the length of a typical experimental session. At the end of this period this group was given the 'conditioned' stimuli, and exhibited an increase in the number of responses, especially to light, an increase closely similar to that found in ordinary forward conditioning. Here the origin of the later responses is much more complicated than the repeated presentation of the unconditioned stimulus, involving possibly attitudinal or other factors. The experiment serves to point out that breaking it down into 3 simultaneously interacting factors may still be much too simple to explain the complex phenomenon of conditioning.

tioning. It is impossible to say what part of the strength of response of typical forward conditioning is due to this temporal contiguity as overlaid on the effect of nonassociative factors, but in Fig. II the area between the curves of the Forward-order Group and the Random-order Group should give a crude graphic approximation.

b. Backward-order as Compared with Random-order Training

A certain similarity is to be noted in the records of groups given these types of training. As shown in Fig. II, aside from the initial superiority of the Backward-order Group over the Random-order Group, the curves closely approximate each other. During the first 3 trials the difference between the two groups tends to approach reliability (chances are 88 in 100 that the difference is a true one), but thereafter the difference is hardly a tendency (C.R. = .32, last 7 trials).

It might be said that the early-appearing tendency toward a difference in favor of the Backward-order Group is the result of the only difference in training given these groups, namely, a regular although unfavorable temporal contiguity in the case of backward-order training. Another explanation can be advanced, however, without recourse to associational factors. From Table I it will be seen that the Pseudo-conditioning Group responded universally to the first criterion sound, and that the response of the Backward-order Group (84.6 percent) was of a somewhat comparable strength. It was concluded earlier in the discussion that the initial high level of response of the Pseudo-conditioning Group was due to the lack of an adaptation factor tending to reduce the level of response. A similar conclusion might be drawn in the case of the Backward-order Group, reasoning from certain facts of stimulus-equivalence. It is well known that the effectiveness of a tone depends upon the pattern in which it is found—the stimulus as an event in the *milieu* of the organism is almost certain not to be the physical event *per se*. In this connection it is germane that in the backward-order training the sound had always been *preceded by a shock*. In the criterion trials the sound is, however, always presented *without* shock, *in a new setting*, and is therefore in some sense a truly new stimulus. If this reasoning holds, then the factor of adaptation in the case of the Backward-order Group would be minimized.

Following this argument, it is assumed that at least the first criterion responses to sound of the Backward-order Group partake of the nature of those of the Pseudo-conditioning Group, and as such are not unqualified evidence of so-called backward conditioning.

c. Forward-order as Compared with Backward-order Training

It is not possible, by comparing groups given these types of training, to isolate any factors except those having to do with the temporal relationship of stimuli, but on this point the comparison is straightforward. Regardless of what factors operate to produce the responses of the Backward-order Group, the effectiveness of forward-order training is clear. We are not at the moment concerned to know whether the results of the Backward-order Group constitute evidence of true conditioning, but only with the reliable difference between forward-order and the next most effective type of training.

Summary

In a typical avoidance conditioning situation, four groups of college students were given forward-order, backward-order, random-order, and pseudo-conditioning training. Number of finger movements in an extinction series of 10 conditioned stimuli was taken as the criterion of strength of response. All groups responded appreciably.

The unconditioned response to sound was not facilitated by forward-order training. It is not clear whether the criterion responses as a result of the other types of training should be classed as facilitated unconditioned responses to the conditioned stimulus. Several lines of evidence point toward the concept of pseudo-conditioning as the better explanation.

There were no observable differences between groups with respect to the unconditioned reaction to shock.

It is argued that the results of groups given random-order and pseudo-conditioning training demonstrate the possibility of the existence of inherent and relatively constant nonassociative factors in a typical conditioning situation which tend to augment or decrement the effect of purely associative factors. These associative factors known to accrue from the typical conditioning juxtaposition of stimuli may overlie, or be modified by, nonassociative factors of one sort or another.

It is suggested that two of these factors are, (1), pseudo-conditioning, an effect arising from repeated presentation of the unconditioned stimulus, and (2), adaptation arising from repeated presentation of the conditioned stimulus. The inference is that an adequate explanation of a set of typical conditioning data should not neglect these less obvious factors. Specifically, in the present experiment, the response strength of a group given forward-order training is to be explained as in some part a direct or indirect result of factors having nothing to do with the temporal relationship between the conditioned

and the unconditioned stimuli, while it may be possible to explain the response strength of the group given backward-order training almost completely in this way.

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CONSCIOUS TIME JUDGMENTS RELATED TO CONDITIONED TIME INTERVALS AND VOLUNTARY CONTROL OF THE ALPHA RHYTHM

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Introduction

In a previous study it has been shown that practically all the classical Pavlovian principles of conditioning can be demonstrated in man by the use of the depression of the occipital alpha rhythm as a conditioned response (**6**). With this technique light was the unconditioned stimulus (UCS) and sound the conditioned stimulus (CS). It was found that conditioned responses involving time intervals (delayed, trace, and cyclic) were quite accurate though anticipatory. This fact suggested the present investigation of the relation of these conditioned responses to conscious time judgments and, further, a method for studying the role of voluntary factors in the control of the alpha rhythm.

It has been shown by Loomis, Harvey and Hobart (**8**) that under hypnosis the occipital alpha rhythm may be blocked as though to light by suggestion of light in a completely darkened room. Other investigators have shown that visual attention (**2**), 'the attempt to see' (**9**), or the 'arousal value' (**5**) of any stimulus is as important as light itself in causing depression of the alpha rhythm. It is clear that the alpha response as recorded in the electroencephalogram is not a simple 'reflex' to light. It can be conditioned as a simple reflex so it must be analogous in some respects. Since the alpha rhythm represents the directly recorded activity of the higher centers one would expect it to be more closely related to voluntary processes. However, it would be necessary for a subject to be capable of estimating time with an accuracy equal to that shown in temporal conditioning of the alpha rhythm if conscious processes play a principal role.

Several studies have shown the possibility of developing voluntary control over a relatively involuntary response by conditioning. In early experiments of Bair (**1**), subjects were taught to move their ears by pairing a voluntary movement (clenching the jaw) with electrical stimulation to the retrahens muscle of the ear. Hudgins (**4**) reports a voluntary CR of the iridic reflex. Steckle and Renshaw (**11**) and Steckle (**10**) were unsuccessful in reproducing Hudgins' results. The 'Aschner phenomenon' (retardation of pulse on pressing

the eyeball) has been conditioned to self-instructed words in children [Kotliarevsky (7)]. It appears from these studies that, under some conditions, certain involuntary responses may be brought under voluntary control by conditioning.

The purpose of the present study is a comparison of the accuracy of conscious time estimation with that of the conditioned response and an attempt to establish voluntary control of the alpha rhythm by conditioning.

Technique

Apparatus.—Brain potentials were recorded by means of a standard amplifier and ink-writing oscillograph. Additional pens indicated various signals (stimuli and manual responses) on the E.E.G. record. A beat frequency oscillator was used for sound stimuli of 700 d.v. per sec. Loudness was kept constant throughout. A 6 volt flashlight bulb, 12 inches in front of the subject's eyes, provided visual stimulation. Manual responses were indicated by means of a push button connected to an electromagnetic marker. All stimuli for the time experiments were controlled from outside the closed room used for the subject.

Subjects.—There were eleven subjects, all adult males. Ten were used for time estimation, and one of these was again used in the voluntary CR experiments. There were two subjects for the latter. All of these subjects had a regular and almost continuous occipital alpha rhythm which responded clearly to light stimulation.

Procedure.—Two electrodes were applied by means of collodion, one on the scalp over the right occiput, the other on the right ear. Monopolar recording of the occipital alpha rhythm was thus provided. The subject was placed on a bed in a completely dark, sound-proof, electrically shielded room.

The technique of establishing the delayed, trace, and cyclic conditioned responses used in this study has been described in a previous report (6). Control trials at the beginning of each experiment demonstrated the absence of alpha responses to the CS. Then conditioning was carried out until at least ten CRs were obtained (reinforcement was usually necessary). An interval of 9.4 sec. was used throughout. After conditioning was complete the accuracy of conscious time estimation was tested. This was done by asking the subject to press the button when he thought the conditioned time interval had elapsed. The conditioned interval was presented each time as a standard for estimation. At least six estimations were obtained for each subject.

Results

Time Estimation

Very little relationship was shown between the accuracy of conscious time estimation and that of all time CRs (delayed, trace, and cyclic). The CR intervals varied within narrow limits and appeared quite constant. Conscious estimates showed less accuracy and wide variations. Quantitative results are presented in Table 1.

The rank correlation between CR intervals and conscious judgment of the same interval of time was $R = -.04$. The CRs were all anticipatory with an average of 8.2 sec. for the 9.4 sec. conditioned interval and showed little variation (S.D. = 0.7 sec.). Time estimations tended to be longer than the conditioned interval ($M = 10.5$ sec.) and showed greater variation (S.D. = 2.5 sec.). Coefficients of variation show clearly the lack of reliability of the time estimations

relative to the conditioned intervals. Relative independence of the two phenomena is demonstrated.

TABLE 1

MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF (1) CR TIME AND (2) VOLUNTARY ESTIMATION OF TIME

Standard Interval 9.4 ± .2 secs.

Subject	M_1	M_2	S.D.$_1$	S.D.$_2$	V_1	V_2
1	9.2	14.4	1.9	3.6	20.3	25.0
2	7.2	9.9	1.6	1.5	22.1	15.2
3	7.9	15.2	.8	3.4	10.1	22.4
4	8.5	6.0	.8	.9	9.4	15.0
5	8.0	9.5	.7	1.7	8.7	17.9
6	7.1	9.3	1.1	4.0	15.5	43.0
7	8.8	9.4	1.8	.7	20.4	7.5
8	9.1	8.0	1.1	.9	12.1	11.2
9	8.7	11.6	.4	3.1	4.6	26.7
10	7.3	12.0	1.1	4.4	15.1	36.7
Means	8.2	10.5	0.7	2.5	8.6	23.8

Spearman's Rank Order $R_{M_1M_2} = -.04$.

Voluntary Conditioned Responses

A conditioned 'voluntary stimulus' was provided by having the subject repeat subvocally the word 'block' and press the switch button at the same time. The pressing of the button was used to provide a record of the voluntary stimulus and it constituted a part of the stimulus pattern. After a certain interval he was to repeat subvocally the word 'stop' and release the button. The interval between 'block' and 'stop' was determined by the subject alone in the sound-proof room. He was given an idea of about the interval desired (10 sec.) before the experiment was started.

A double switch was used by the subject; one contact caused a signal to appear on the record and the other turned on the light stimulus. The experimenter, outside the room, was able to break the light circuit so that the voluntary stimulus, repeating 'block' and pressing the button, could occur without reinforcement in control and test trials. Several control trials were first given and the circuit closed for conditioning.

The voluntary stimulus before conditioning had no appreciable effect on the alpha rhythm (Fig. 1). After conditioning the voluntary stimulus alone produced a depression of the alpha rhythm as complete as that in response to light but usually of shorter duration. Voluntary blocking of the alpha rhythm was established.

The two subjects differed widely in their rate of conditioning, one requiring five and the other eighty-four trials before a single CR was

established.[1] Five consecutive CRs were obtained in one subject before extinction and three in the other. Spontaneous recovery was not tested.

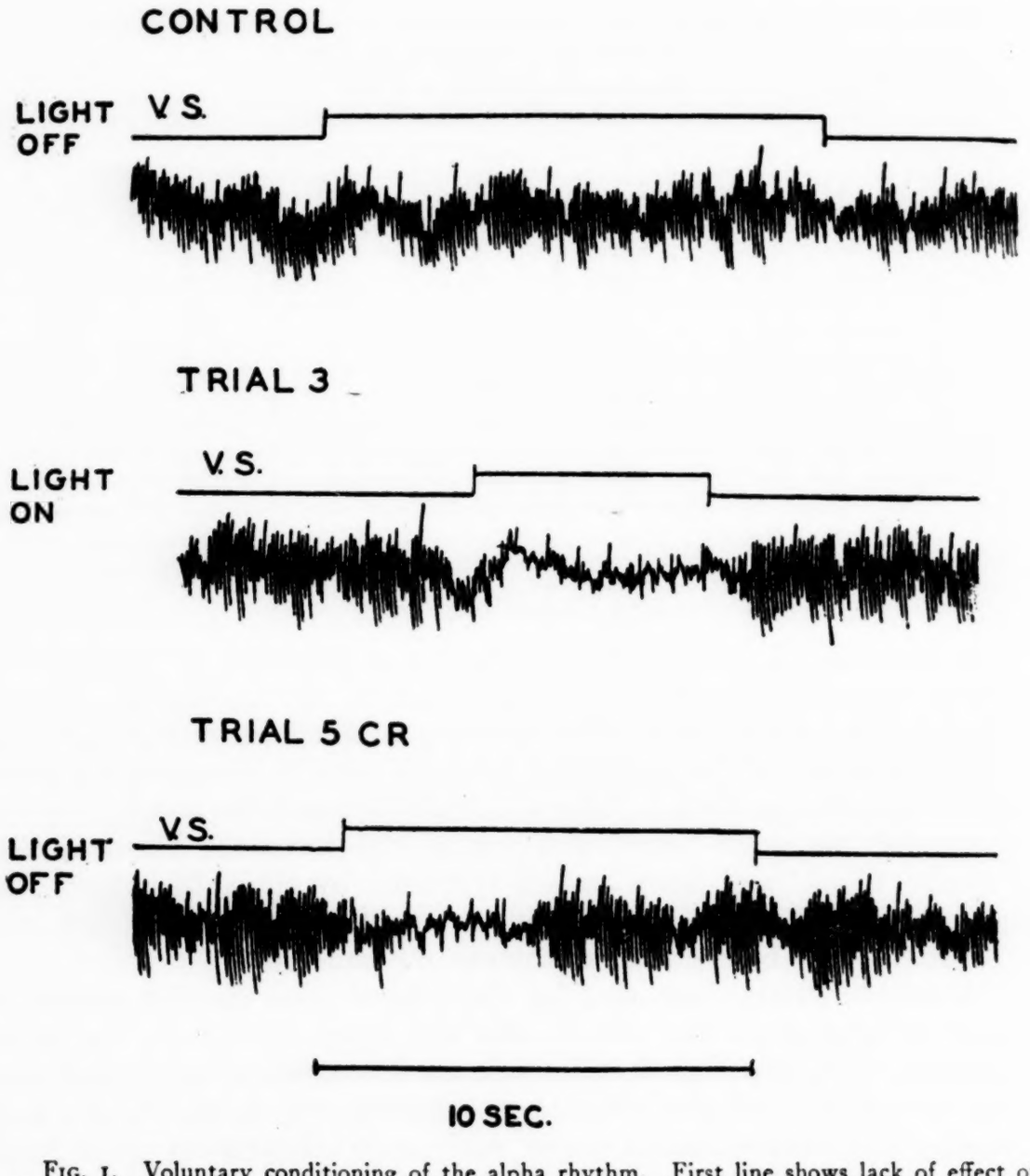

FIG. 1. Voluntary conditioning of the alpha rhythm. First line shows lack of effect of voluntary signal (V.S.) before conditioning. Second line is the conditioning trial with light. Third line shows conditioned voluntary response with no light stimulus. Note short duration of alpha block in voluntary CR relative to duration in UCR.

In the conditioned response a zero or negative latency with respect to the manual signal was often observed. This probably indicates that the voluntary stimulus, namely the subvocal 'block,' and preparation for manual response (proprioceptive) were sufficient

[1] The number of trials includes test trials.

to produce the CR. The fact that the alpha block was of shorter duration than the manual signal, would indicate that the subvocal 'stop' and preparation for release of the button were adequate, as a stimulus, for return of the alpha rhythm (Fig. 1).

Discussion

The independence of conscious time judgment and the conditioned blocking of the alpha rhythm to time intervals show that voluntary factors do not determine this response. An involuntary time mechanism must be operating.[2] Under the conditions of this experiment CR of the occipital alpha rhythm, presumably representing cortical activity, is shown to be independent of conscious processes.

On the contrary, with a different method of conditioning it is possible to develop voluntary control of the alpha response. This response did not require several successive stages of conditioning as were necessary in the studies of Hudgins (4) and in those of Kotliarevsky (7) where CRs were first established to a bell, etc. It differs also from the voluntary pupillary response of Hudgins in that extinction was readily produced. An important difference in technique is the inclusion of the manual response but in all of our experiments the conditioned alpha response seems to be quite unstable.

With reference to the influence of voluntary factors Hilgard and Marquis (3) have stated:

"Conditioned responses may fall at any point along the involuntary-voluntary scale, depending upon the particular experimental situation in which they are established." The CRs were here established in two different types of experimental situations: (1) Where the subject had no control over the stimulus and (2) where he had complete control. The resulting CRs are then at opposite points on the 'involuntary-voluntary scale.' The response itself seems to be the same. The differentiating factor is the type of stimulus to which the CR was established.

Summary

1. The time interval in delayed, trace, and cyclic conditioned responses of the occipital alpha rhythm was shown to be more accurate and not related to conscious estimations of the same time interval. It is concluded that an involuntary time mechanism is operating in this response.

2. Conditioned response of the occipital alpha rhythm was established to a voluntary stimulus, subvocal repetition of the word

[2] This mechanism may be similar to that operating in determining the accurate timing of post-hypnotic suggestion.

'block' with voluntary manual response. In this manner voluntary control of the alpha rhythm was established.

3. The same response, blocking of the alpha rhythm, was conditioned in one way independent of voluntary control and in another way under voluntary control. The differentiating factor was the type of stimulus to which the conditioned response was established.

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STUDIES OF THE SENSATION OF VIBRATION: I. VARIABILITY OF THE VIBRATORY THRESHOLD AS A FUNCTION OF AMPLITUDE AND FREQUENCY OF MECHANICAL VIBRATION [1]

BY G. K. YACORZYNSKI AND MEYER BROWN

Northwestern University Medical School [2]

In order to establish norms for mechanical vibratory thresholds for practical clinical purposes and to initiate experimental studies of this sense modality certain questions in relation to the fluctuations of the thresholds must first be adequately considered. The exigency of time in clinical diagnosis makes it necessary to obtain threshold determinations with the minimal number of readings. Obviously the time consuming ordinary psycho-physical methods of obtaining a large number of determinations are not adequate for this purpose. There is also no good reason for believing that two threshold determinations (7) or the 'clinical method' as such gives a good approximation to the actual threshold of the individual under the conditions studied. Therefore, as a preliminary step in the study of vibratory thresholds the following two questions must first be considered: 1. How many threshold determinations on one subject are necessary at one testing period to obtain a stable threshold of the individual in relation to the group? 2. How great is the fluctuation of this threshold when measured at different time intervals? These two questions on reliability of the vibratory threshold as a function of amplitude and frequency of stimulation are considered in the present study.

Apparatus

Descriptions of instruments used for the study of vibratory sensations which meet the criterion of satisfactory precision have been published by Fessard (2), Geldard and Gilmer (4), Goodfellow and Krause (6), Knudsen (7), and others. The set-up [3] used by us, the description of which is given in Figs. 1 and 2, is constructed on the same principles as the apparatus used by some of these individuals. It consists of two units:

1. A unit for driving the stimulating pointer, which consists of a vacuum tube oscillator, a three stage radio amplifier, and an electro-dynamic speaker. This set-up, except at resonance, gives sinusoidal waves over a wide band of frequencies to the stimulator mounted on the core

[1] This study is a continuation of the work done by Dr. Lewis J. Pollock (8). The authors wish to express their appreciation for his coöperation.

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[3] The writers wish to express their appreciation to Mr. Benjamin B. Bauer of Shure Brothers, Chicago, and to Mr. Earle Choate at Northwestern University Medical School for technical advice, as well as the construction of the apparatus.

of the electro-dynamic speaker. Since, however, above the frequency of 1000 d.v. the sensitivity to vibratory stimuli as a function of amplitude decreases rapidly, and since the amplitude of the vibrator decreases as the frequency is increased with a constant energy input, it is possible to measure the threshold only up to approximately 3000 d.v. on the most sensitive areas of the body.

2. A unit for recording the purity of the wave and the amplitude of the vibrating stimulator which consists of a rochelle salt crystal housed in a cell which is mounted on the stimulating pointer, a high gain amplifier, an oscilloscope and voltmeters.

The measurement of the wave characteristics of the stimulator while it is in use is an essential requirement in the determinations of vibratory thresholds, since the purity of the wave or the dampening which might result when contact is made with the skin cannot be determined by measuring the electrical input of the electro-dynamic speaker. This factor has been taken into consideration by Fessard (2) and Geldard and Gilmer (4). The latter authors used a piezo-astatic phono pick-up, the needle of which rested on the vibrator used for stimulation. The displacement of the needle during the movement of the stimulator created an e.m.f. in the crystal which, with proper amplification, could be read on an oscilloscope. We have found that an inertia-type crystal described by Baumzweiger (1) is more satisfactory for this purpose. In this set-up the rochelle salt crystal is inclosed in a cell which is mounted on the stimulator (Fig.

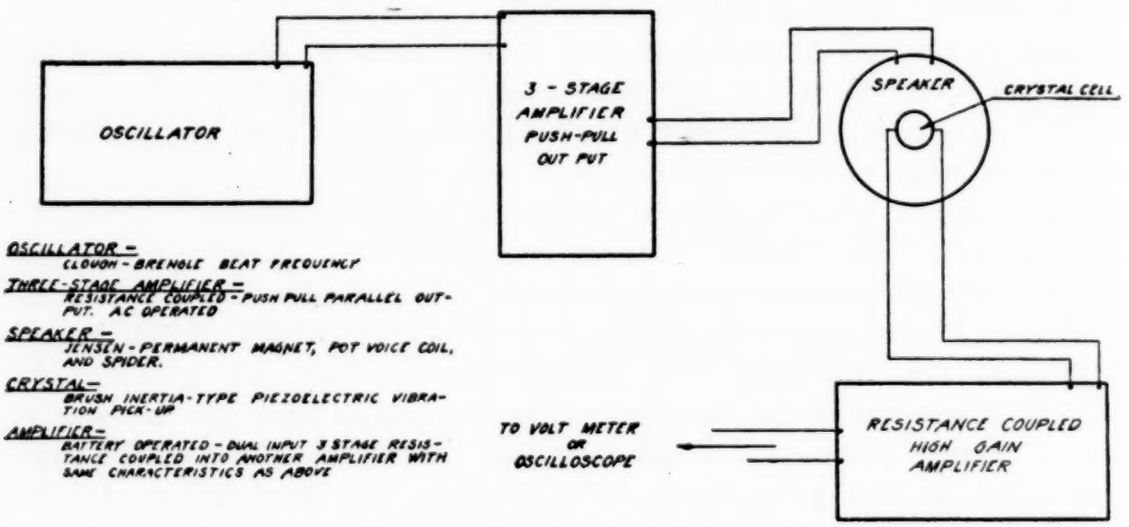
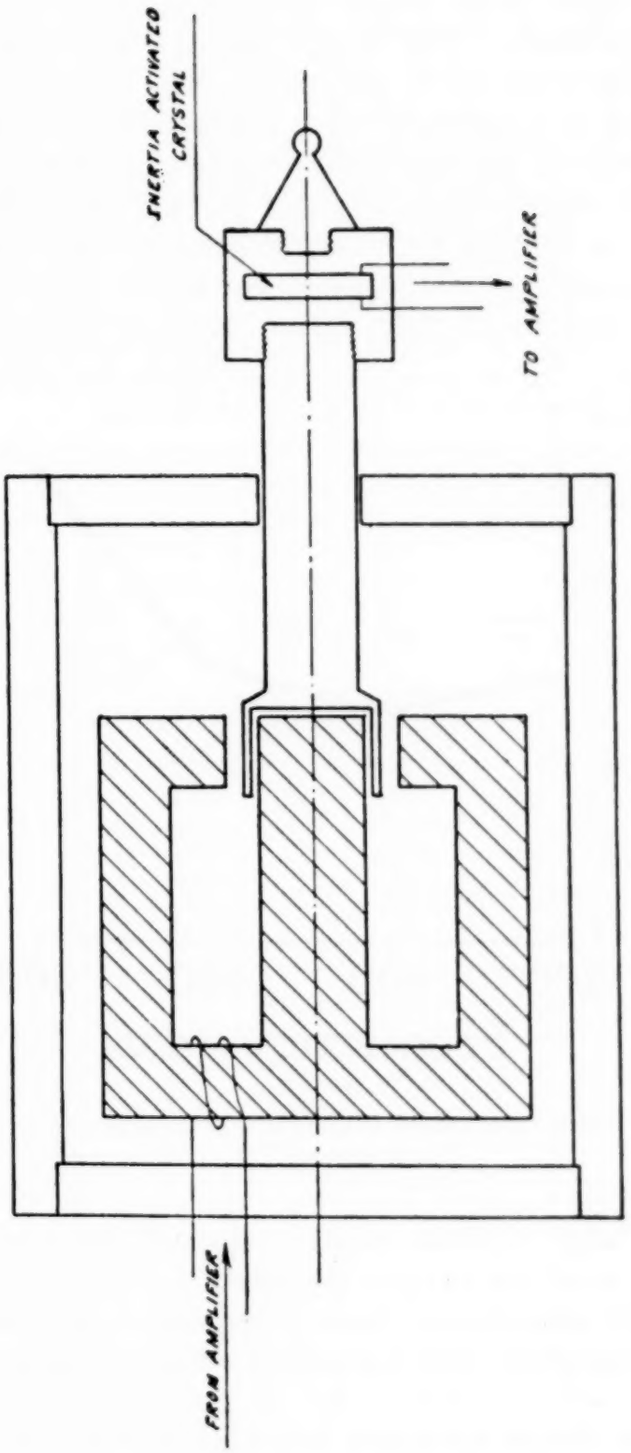

OSCILLATOR
3 - STAGE AMPLIFIER PUSH-PULL OUT PUT
SPEAKER
CRYSTAL CELL
OSCILLATOR - CLOUGH - BRENOLE BEAT FREQUENCY
THREE-STAGE AMPLIFIER - RESISTANCE COUPLED - PUSH PULL PARALLEL OUTPUT. AC OPERATED
SPEAKER - JENSEN - PERMANENT MAGNET, POT VOICE COIL, AND SPIDER.
CRYSTAL - BRUSH INERTIA-TYPE PIEZOELECTRIC VIBRATION PICK-UP
AMPLIFIER - BATTERY OPERATED - DUAL INPUT 3 STAGE RESISTANCE COUPLED INTO ANOTHER AMPLIFIER WITH SAME CHARACTERISTICS AS ABOVE
TO VOLT METER OR OSCILLOSCOPE
RESISTANCE COUPLED HIGH GAIN AMPLIFIER

FIG. 1. Diagram of the apparatus for the study of mechanical vibration.

2). One end of the crystal is unattached so that the movement of the cell, due to the inertia of the unattached end of the crystal, creates an e.m.f. The advantages of this method over having the needle rest on the vibrator are: 1. That a stationary body to serve as a reference point is not necessary, and therefore, no displacement of the needle can result from slight jarring of the instrument; 2. That since the potential created in the crystal is proportional to the square of the frequency of vibration it is necessary to calibrate the amplitude for only one frequency in order to obtain calibration curves for the whole range of frequencies at which the vibrator is to be used; 3. That the crystal remains relatively unaffected by ordinary temperature changes.

To calibrate the potential created in the piezoelectric crystal against the amplitude of the vibrating stimulator we used a 20 to 1 lever (*cf.* 4, 7) with a micrometer screw, graduated in .01 of a mm, mounted against the longer arm of the lever. The shorter arm of the lever is brought against the stimulating point until contact is made, and an electric circuit from a 1.5 volt dry cell battery is closed, producing a click in the ear-phones placed in the circuit. The end of the lever is then withdrawn from the vibrator which is set in motion. The lever is again brought to the stimulator until the circuit is closed. The difference between the micrometer readings when the stimulator is stationary and when it is vibrating gives the amplitude reading. The potential output of the crystal after amplification can be read either on a meter or an oscilloscope. From one reading at any frequency (we used the frequency of 200 d.v.) it is possible to plot graphs for other frequencies from the relationship, as pointed out, that the e.m.f. created in the piezoelectric crystal is proportional to the square of the frequency of vibration.



Detail of speaker and crystal

FIG. 2. Diagram of the attachment of the aluminum housing, containing the rochelle salt crystals, on the core (stimulator) of the electro-dynamic speaker.

Results

Reliability of Group Testing.—The vibratory thresholds of the finger tip of the right index finger were determined for 20 subjects, 10 men and 10 women. The mean age of the subjects was 35.4 years, with a range from 18 to 57 years. The threshold determinations as a function of amplitude were made with a stimulator .5 cm in diameter for each of the four following frequencies: 200, 400, 600, and 800 d.v. To obtain the threshold for a certain frequency the vibrator was set in motion at either a greater amplitude than the individual's threshold (as determined by a few preliminary trials) or below the threshold and then varied in small steps of amplitude

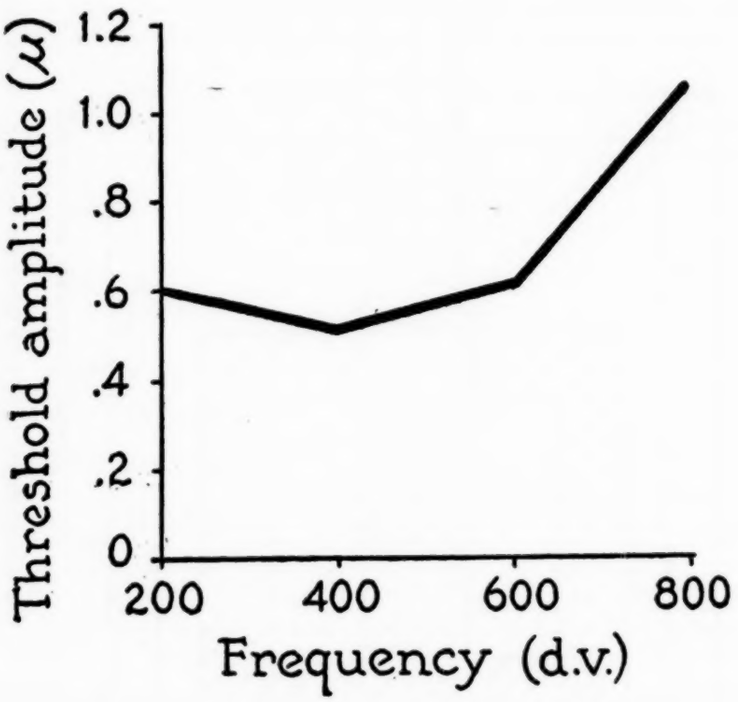


Fig. 3. Threshold amplitudes expressed in thousandths of a millimeter at four frequencies for 20 subjects.

differences. The finger tip was brought against the vibrator at each amplitude setting until the subject reported that he felt the presence (or absence) of the sensation. Ten threshold determinations were made at each frequency for each subject in a descending and ascending order.

The amplitudes of the vibratory stimulus at the threshold values for the four frequencies are shown as averages for the 20 subjects in Fig. 3. The general shape of this curve agrees very closely with the lower threshold values obtained by other experimenters (*cf.* **3**).

To obtain a measure of the stability of the thresholds, Pearson's correlation coefficients were computed between the first five and the

last five threshold determinations of the subjects. These correlation coefficients, corrected for attenuation, for the four frequencies were as follows: .94, .99, .96, and .97. Using the Spearman-Brown prophecy formula we find that if only four threshold determinations are used the reliability is still very high, the correlation coefficients being of the following magnitudes: .87, .97, .90, .92. Thus in answer to our first question as to the minimal number of threshold determinations which must be made in order to obtain a consistent score for a subject at one setting we find that four are sufficient.

TABLE 1

THE AVERAGES OF 10 AMPLITUDE THRESHOLDS AT 4 FREQUENCIES FOR 4 SUBJECTS, AND THE STANDARD DEVIATIONS OF THE DISTRIBUTIONS FOR THE 10 THRESHOLD DETERMINATIONS

Subject	Frequency in Double Vibrations							
	200		400		800		1000	
	Threshold (μ)	S.D.	Threshold (μ)	S.D.	Threshold (μ)	S.D.	Threshold (μ)	S.D.
Right Index Finger								
H	.40	.063	.33	.083	.92	.106	1.06	.122
B	.39	.120	.41	.126	.67	.184	.91	.148
Y	.31	.096	.25	.050	.66	.082	1.04	.163
G	.45	.137	.39	.155	.59	.129	.79	.200
Ave.	.39		.35		.71		.95	
Left Index Finger								
H	.25	.052	.20	.047	.32	.106	.67	.267
B	.37	.116	.24	.103	.63	.115	1.19	.137
Y	.42	.099	.25	.025	.68	.144	1.26	.299
G	.33	.057	.30	.096	.55	.171	.74	.101
Ave.	.34		.25		.55		.96	

It is also of value to know what relationship exists between the vibratory thresholds of the subjects at the different frequencies. In other words, the question is raised whether the threshold at one frequency will predict a subject's threshold at other frequencies. To answer this question the thresholds of the subjects at 200 d.v. were correlated with their thresholds at 800 d.v. This correlation coefficient was .72, which shows some agreement as to the relative ranking of the thresholds of each subject at these two frequencies, but the relationship is not sufficient for adequate predictive purposes, since

the error involved in such a prediction would be reduced by only about 30 percent.

Quotidian Variability of Threshold of Individual Cases.—To determine how great a variability of the threshold at different intervals can be expected for individual cases the vibratory thresholds of 4 male subjects (2 medical students, and 2 instructors) were determined at intervals of from 3 to 7 days. The experiment consisted of 10 such sessions and during each session 4 determinations of the threshold in terms of amplitude were made, alternated in a descending and and ascending order, at each of the following frequencies: 200, 400, 800 and 1000 d.v. The finger tips of the right and left index fingers were used.

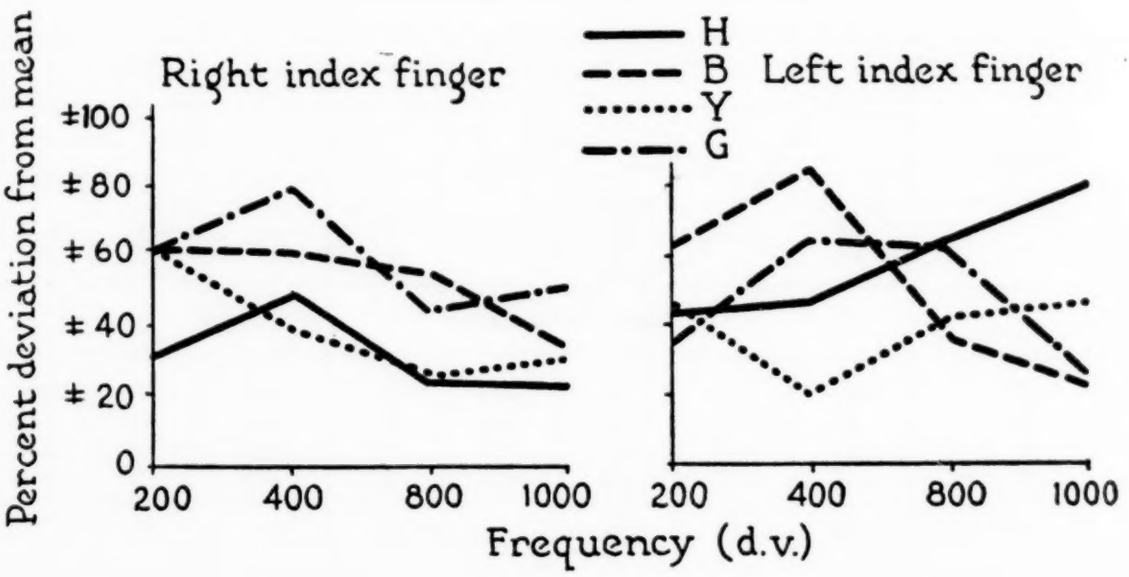


FIG. 4. The standard deviations (Table 1) of 10 amplitude thresholds at frequencies of 200, 400, 800, and 1000 d.v. for each of the 4 subjects were multiplied by 2 and expressed as percent of the deviation from the average threshold of the 10 determinations. The 0 value on the ordinate represents the relative value of the means for each subject at the 4 frequencies for both the right and left index finger tips. The curves show the percent deviation from the mean of twice the standard deviation at the different frequencies for each subject.

Table 1 gives the average thresholds of the 10 sessions (4 threshold determinations for each session) of the right and left index fingers of the 4 subjects at each of the 4 frequencies used, and the standard deviations of the 10 measures. The average threshold values for these 4 subjects are lower than that of the 20 subjects whose results are plotted in Fig. 3. These differences can be due to the fact that the 4 subjects used in this part of the experiment had received practice in preliminary experiments whereas the group of 20 subjects had not, and/or they can be due to age, weight, or other physiological factors which influence the vibratory threshold, and which would

differ in a homogeneous group of subjects as compared with subjects selected from the general population.

The deviations of the 10 threshold determinations show that wide fluctuations of the thresholds can be expected when the measurements are made at intervals separated by a few days, a fact which is more strikingly illustrated by Fig. 4. To obtain the curves of Fig. 4 the standard deviations for each of the frequencies of each subject (Table 1) were multiplied by two, and then expressed as a percentage of the change from the mean of the 10 thresholds. These limits are chosen because the probability of a threshold determined by 4 readings lying beyond these limits (either in a positive or negative direction) is about 5 out of 100. The figure shows that these limits range from 85 to 20 percent. These results agree with Goodfellow (**5**) who has reported wide fluctuations in the vibratory threshold determined on different days.

Summary

The purpose of this study was to determine the minimal number of vibratory thresholds, as a function of amplitude of stimulation at different frequencies, which are necessary for adequate reliability, and to measure the quotidian variability of the threshold.

For a group of 20 subjects the split-half Pearson's correlation coefficients (corrected for attenuation) for 10 threshold determinations, using a stimulator .5 cm in diameter, of the right index finger tip at frequencies of 200, 400, 600, and 800 d.v., were .94, .99, .96, and .97. In making group studies of the vibratory thresholds 4 determinations are sufficient in order to obtain a high degree of reliability, since the correlation coefficients for 4 threshold readings are .87, .97, .90, and .92.

The correlation between the thresholds at 200 and 800 d.v. for the 20 subjects was .72. This shows some relationship between the thresholds at the different frequencies but the relationship is not sufficiently high for adequate predictive purposes.

The thresholds of 4 subjects were determined at intervals of from 3 to 7 days. Ten such sessions were used with 4 threshold determinations for each session. Both the right and left index finger tips were stimulated at frequencies of 200, 400, 800, and 1000 d.v. There were large fluctuations of the thresholds of the subjects on the different days. These results mean that it is necessary to study the vibratory threshold of an individual case over a number of days in order to get a good approximation of his actual threshold under the conditions studied.

(Manuscript received November 22, 1940)

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STUDIES IN THERMAL SENSITIVITY: 15. EFFECTS OF STIMULUS-TEMPERATURE IN SERIATIM WARM-MAPPING

BY WILLIAM LEROY JENKINS

Lehigh University

In a previous article, the effects of stimulus-temperature in seriatim cold-mapping were reported.[1] It was found that high correlations could be established between cold-mappings at widely different temperatures, primarily because changes in stimulus temperature below about 23° C. made very little difference in the appearance of the maps. The hypothesis was advanced that these results could be explained in terms of varying concentrations of minute cold-receptors which differ somewhat in their limens, but are all-or-none in action once the limen has been reached.

Procedure

In the present investigation, a similar problem has been studied in seriatim warm-mapping, which was carried out in substantially the same manner. A checkerboard pattern of 3 × 3 mm squares, stamped on the volar surface of the left forearm, was mapped 12 times, alternately with the standard temperature (44°) and one of the comparison temperatures (36½°, 38°, 41°, 47° or 50°). The four-hour experimental session was divided into two parts with a two-hour rest period between. The three members of each group acted in turn as subject, experimenter and recorder. There was an average recovery period of fifteen minutes between successive mappings of the same area.

Subjects reported 0 for neutral, 1 for weak, 2 for medium and 3 for strong warmth. The score for each square was determined by adding up the 6 numbers reported; thus the maximum possible score was 18 and the minimum 0. Correlations by the product-moment formula were computed: (*a*) for internal consistency on the basis of odd and even totals; (*b*) for intercorrelation between temperatures, on the basis of corresponding scores at the standard and comparison temperatures.

Results

Table 1 shows the correlations for internal consistency, and the intercorrelations between temperatures. The indicated internal consistencies at 41°, 44° and 47° compare very favorably with similar figures obtained for cold—about .78 for the median, compared with .80 or slightly better usually obtained with cold. But at 38°, the median drops to .70, while at 36½° and 50° it is .60. In the case of 50° stimulation, the results from 6 subjects had to be discarded because 'pain' was frequently reported.

The intercorrelations present quite another story. In contrast to the results with cold, here we find *no* high intercorrelations with a

[1] Jenkins, W. L., Studies in thermal sensitivity: 13. Effects of stimulus temperature in seriatim cold-mapping, *J. exp. Psychol.*, 1939, **25**, 519–527.

6° change in stimulus-temperature, and very few with a 3° change. For the purpose of further analysis, those subjects were selected who showed satisfactory internal consistency at the standard temperature and the median or higher consistency at the comparison temperature. A scattergraph was plotted for each comparison temperature, combining the results for these selected subjects. These scattergraphs are shown in Fig. 1. Ordinates are scores at standard temperature; abscissæ are scores at comparison temperatures. Each complete black circle represents 10 cases, with fractional parts proportionate. The scores are grouped into seven step intervals: 0–1, 2–3–4, 5–6–7, 8–9–10, 11–12–13, 14–15–16, 17–18. The small scattergraph at the upper right indicates the internal consistency at 44° C. It will be noted that a 3° change in temperature causes a wide spread; while 6° or more makes the results almost unpredictable. This brings out graphically what might be expected from the low intercorrelation coefficients previously cited.

TABLE 1

CORRELATIONS

Internal Consistency (Odd-Even)

Temp. ° C.	.00 .69	.60 .69	.70 .79	.80 .89	.90 1.00	Total Cases	Median Correl.
36½	9	4	3	2	—	18	.60
38	2	2	3	2	—	9	.70
41	4	3	6	7	1	21	.78
44	12	9	21	20	6	68	.78
47	3	3	1	5	2	14	.77
50	3	—	2	—	1	6*	.60

Intercorrelation with 44° Scores

Temp. ° C.	.00 .50	.60 .69	.70 .70	.80 .89	.90 1.00	Total Cases	Median Correl.
36½/44	14	3	1	—	—	18	—
38/44	7	1	1	—	—	9	—
41/44	3	8	6	4	—	21	.69
47/44	5	2	4	3	—	14	.70
50/44	5	—	1	—	—	6	—

* 6 other cases discarded because of frequent reports of pain.

Figure 2 shows individual maps for six subjects. The height of the black bars indicates the magnitude of scores at the standard temperature, while the stippled bars show the scores at comparison temperatures. These maps deserve a brief individual examination.

AEJ.—In spite of high internal consistency at both temperatures, this subject shows virtually no intercorrelation between 44° and 38°. This is borne out by the appearance of the map. At 44°, there

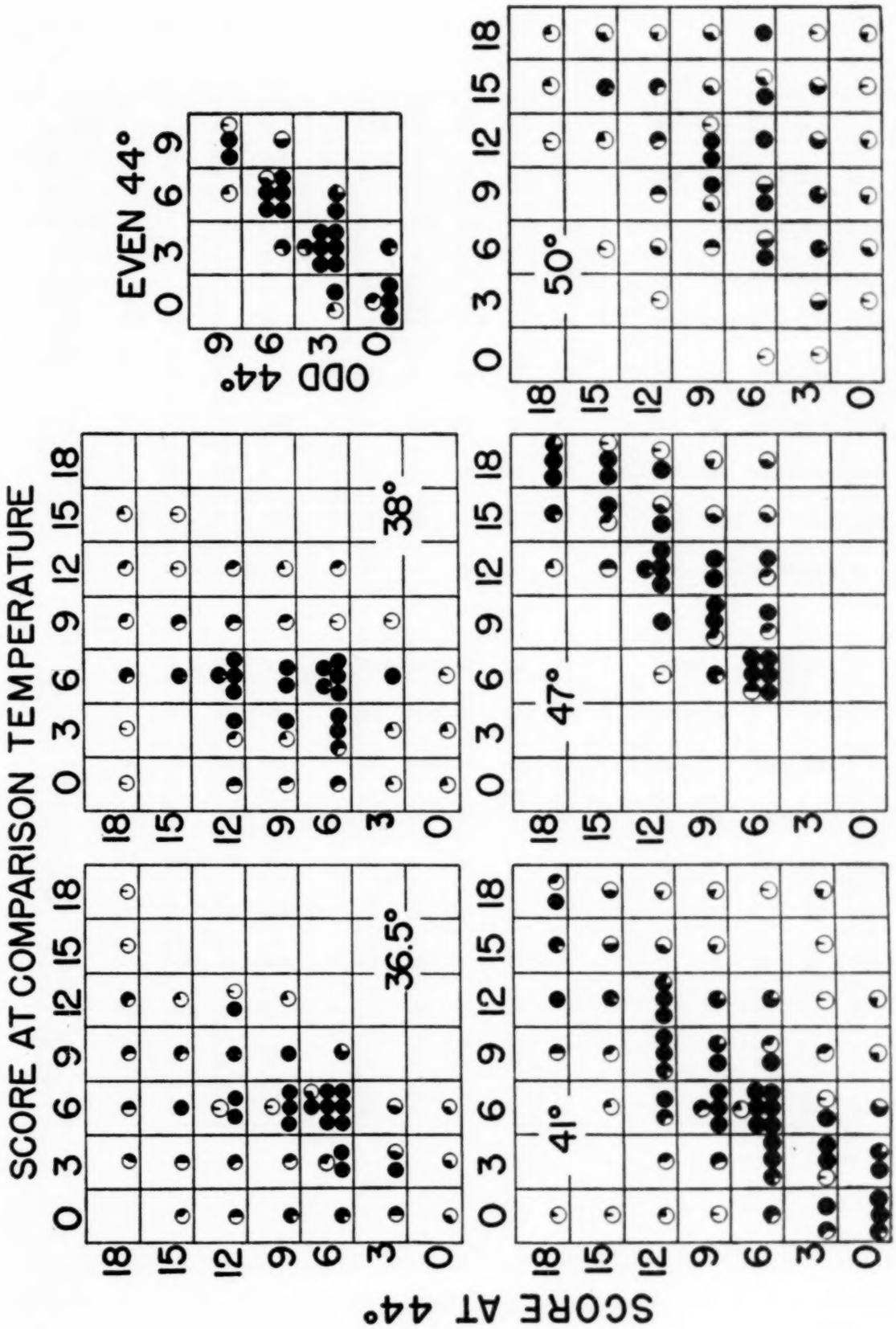
SCORE AT 44°
SCORE AT COMPARISON TEMPERATURE
0 3 6 9 12 15 18
36.5°
41°
47°
50°
38°
EVEN 44°
ODD 44°

FIG. 1

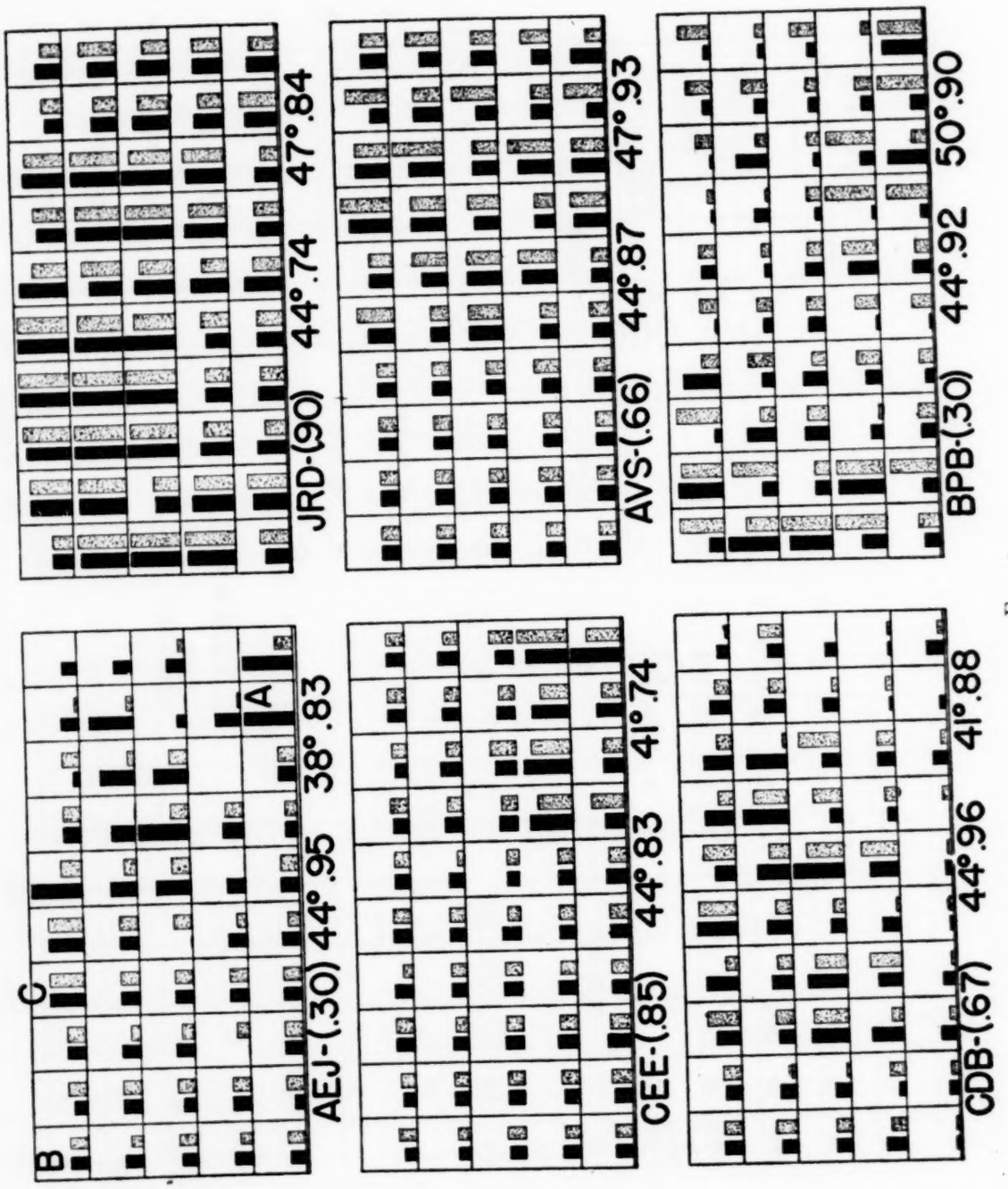
JRD-(90) 44°.74 47°.84
AVS-(.66) 44°.87 47°.93
BPB-(.30) 44°.92 50°.90
AEJ-(.30) 44°.95 38°.83
CEE-(.85) 44°.83 41°.74
CDB-(.67) 44°.96 41°.88
A
B
C

FIG. 2

is a streak of high sensitivity running diagonally across the upper right-hand half, with the remainder of the area fairly uniform. But at 38°, there is no simple reduction from this pattern. The only high sensitivity is in the middle of the top row. The left-hand half is much the same as it was at 44°, while the right-hand half has dropped considerably, in many squares to complete zero. Viewed as a whole, the black and the stippled bars appear to present two totally independent distributions.

CEE.—This presents what appears to be a typical picture when a high intercorrelation is found. The high coefficient is caused not by a uniform reduction, but merely by the fact that the scores are practically identical at the two temperatures.

CDB.—In contrast to CEE, this subject shows a poor intercorrelation in spite of very high internal consistency at both 44° and 41°. As in the case of AEJ, it is difficult to conceive of the 41° map as a simple reduction from 44°.

JRD.—Like CEE, this subject shows practically the same scores at 44° and 47°, with a consequently high intercorrelation.

AVS.—This resembles CDB; there is high internal consistency, but little resemblance between the maps.

BPB.—This resembles AEJ; high internal consistency, but very low intercorrelation, and apparently two quite independent distributions.

These six cases typify the general results. When high intercorrelations are found, it is merely because the two sets of scores are substantially identical; *i.e.*, the change in stimulus-temperature has had little or no effect. Whenever there is a marked change in score levels, high intercorrelations are notably absent. Never do we find a general raising or a general lowering of all scores proportionately.

Discussion

The chief significance of these findings may be illustrated very simply by reference to the three squares marked *A*, *B* and *C* on the map for AEJ in Fig. 2. (These are simply very striking examples of what may be found throughout all the maps.) At 38° (stippled bars) the scores for these squares are: *A*—0, *B*—6, and *C*—12. At 44° (black bars), they are *A*—18, *B*—6 and *C*—12. With a 6° rise in stimulus-temperature, *A* has gone up from 0 to 18, while *B* and *C* have remained unchanged.

This is an experimental demonstration of what we might call an *all-or-none* kind of response. At 38°, squares *B* and *C* are already contributing their *all*—at least, an increase to 44° adds nothing to the experienced intensity. For square A, on the other hand, 38° is below the limen and the response is zero. But somewhere between

38° and 44°, the limen is passed and the response at 44° is actually higher than that of either *B* or *C*.

To explain these experimental facts in terms of receptor action, it appears obligatory to assume that the *receptors* in *B* and *C* are giving their *all* at 38°—so that an increase to 44° can add nothing. Clearly, there is no graded response between 38° and 44°. The receptors in *A*, on the contrary, are giving nothing at 38°, but more than either *B* or *C* at 44°. If a graded response occurs between 38° and 44°, the gradient must be very steep.

Critical from the standpoint of theory is the *lack* of graded response in *B* and *C*. If this is found to be a general rule, it immediately shuts out the traditional 'warm spots' as receptor units. Typically, only one or two clear 'warm spots' can be found in a square cm. on the volar surface of the forearm, and other variations in the region are explained on the basis of differing thermal conduction to these one or two receptors. But if the 'warm spot' is incapable of graded response, variation in thermal conduction would be meaningless. All of the surrounding area which depended upon that 'warm spot' would have to show the same score at the spot—or else zero. For the same reason, the many variations in score which are found experimentally with changes in stimulus-temperature simply could not happen.[2]

These experimental results, however, are readily explained in terms of the *concentration theory; i.e.*, that variations in experienced intensity are based on varied concentrations of all-or-none receptors. In square *A*, there is a dense concentration of receptors, but of a high liminal level. 38° does not affect enough of them to result in an experience of warmth. 44° excites them in great abundance, and maximal warmth is reported. In square *B*, there is low concentration of receptors, but of a low liminal level; so that they are all set off by the time 38° is reached, and further increase in stimulus-temperature is unavailing. In square *C*, there is a similar situation—except that the concentration is greater and the experienced intensity higher than at *B*. In any square of any map, the relative intensities at any two stimulus-temperatures are thus dependent upon the concentrations of receptors which are active at the two temperatures.[3]

It may be objected that the concentration theory requires the assumption of a large number of receptors, and that with large numbers we should expect to find chance distribution of concentrations and liminal levels. This is a sound objection from a statistical

[2] It has already been shown that the 'warm spot' theory does not happily explain the results obtained in size-comparisons. See: Jenkins, W. L., Studies in thermal sensitivity: 14. Part-whole relations in seriatim warm-mapping, *J. exp. Psychol.*, 1940, **27**, 76–80.

[3] For the sake of simplicity, the question of whether individual receptors vary in 'strength' will not be treated here. This has already been discussed in connection with cold. See *op. cit.*

standpoint. Physiologically, however, the distribution of concentrations of receptors might certainly vary with nerve supply; while liminal levels might vary regionally because of differences of tissue conditions, circulatory supply and similar factors. Meanwhile, it seems that only such a *flexible* scheme can account for the experimental facts.

Summary

Seriatim mapping alternately with a standard temperature (44°) and a comparison temperature (36½°, 38°, 41°, 47° or 50°) gives results which cannot be readily explained in terms of the traditional 'warm spot' theory. In the same map, some scores remain totally unchanged, while others are changed sharply. General increases or decreases over the map as a whole are notably absent. These experimental results, however, are in accord with the concentration theory: *i.e.*, that variations in experienced intensity of warmth are based on varied *concentrations* of receptors, which differ in their liminal level, but are all-or-none in action once the limen is passed. The experienced intensity depends upon the concentration of receptors active at that temperature.

(Manuscript received December 14, 1940)

A NOTE ON THE BARTLEY EFFECT IN THE ESTIMATION OF EQUIVALENT BRIGHTNESS[1]

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Introduction

It is well established that the sensory resultant of intermittent photic stimulation at rates above a critical frequency of alternation of the light and dark phases is fusion, with an apparent brightness of the same flux of light distributed uniformly throughout the cycle (Talbot-Plateau law). Exceptions to this principle have been reported, however, for very low intensities by Fick (**9**), for high intensities by Grünbaum (**10**), and for figures which fail to satisfy certain conditions of 'simple structure' or 'good configuration' by Hartmann (**14**). For frequencies of intermittent light below fusion the sensory resultant is flicker. Since the total luminous flux of regularly intermittent light is independent of flash (cycle) frequency, it has been rather generally assumed that apparent brightness within the range of flicker could likewise be expressed directly as a function of the product of the luminous flux and the time, *i.e.*, independently of flash frequency. However, evidence has recently become available which indicates that this assumed relationship does not hold and thus forces re-examination of certain aspects of the general problem of brightness vision.

Brücke (**7**) reported in 1864 that white sectors on a black and white disc when alternating at an average critical speed of 17.6 cycles per second appear brighter than when stationary. The significance of Brücke's discovery of brightness *enhancement* for a critical frequency of intermittence went unrecognized until the matter was re-opened recently by the investigations of Bartley (**3**) (**4**) (**5**). Using serial flashes of light, Bartley has found that very soon after flash frequency falls below critical flicker frequency the apparent brightness value of the field intermittently illuminated begins to rise until it reaches, then exceeds a level equivalent to that obtained with steady illumination. The maximum enhancement is reached at 8 to 10 flashes per second (rather than at the average of 17.6 per second as described by Brücke for rotating discs). With reference to the brightness produced by steady illumination, the ap-

[1] The Otho S. A. Sprague Memorial Institute and Division of Psychiatry, Department of Medicine, University of Chicago.

parent brightness at maximal enhancement is the reciprocal of the fused or Talbot brightness of the intermittent fields (3) (4).

Since the conditions for producing maximal enhancement of apparent brightness of an intermittent field were first described by Bartley's experiments and could scarcely have been discovered by the conditions of Brücke's study, it seems proper henceforth to refer to the phenomenon in question as the Bartley effect.

Interpretation of the Bartley Effect

Bartley has concluded that the effect of brightness enhancement is probably dependent upon an intrinsic periodicity in the visual pathway (3). He has noted the correspondence of the frequency of 8 to 10 flashes per second, resulting in maximal enhancement with the frequency commonly found for the alpha waves of the human electroencephalogram. According to Bartley, both phenomena occur at a 'resonant' frequency, produced by a rhythmic mechanism in the brain, probably in a similar relationship to that which Bishop and he (1) (2) (6) have found for the brain of the rabbit. They found a coincidence at a rate of five per second between the alpha waves from the visual cortex of the rabbit and the appearance of certain components of the total cortical response to optic nerve stimulation. Bartley concluded that for the rabbit five per second was the fastest rate at which any single set of elements working as a unit could be reactivated maximally from the periphery. Stimuli applied at faster rates were found to be effective but they produced waves of smaller amplitude in the visual cortex (2).

Bartley holds that the enhancement effect is probably not produced by a photochemical mechanism since it is difficult to see how two opposing processes producing a *lower* concentration of the light product x required to give the Talbot effect could, at a lower rate of alternation between light and dark, produce an *increased* concentration of substance x required to give enhancement of apparent brightness (3). Even though this paradox should prove to be more apparent than real there would remain a third possible source of the enhancement effect which Bartley has considered but not explored.

It seems likely that one effect of intermittent photic stimulation upon the eye is to 'drive' the pupillary and accommodative mechanisms, although satisfactory evidence on this point is lacking. Failure of these mechanisms to 'follow' flash frequencies (due possibly to physiological limits for synergic action, or to 'natural' periods of synergic oscillation) might result in the case of the pupil in the admission of relatively more light at certain frequencies or in the alteration of the area over which the light is distributed on the retina

in the case of the accommodative mechanism. Should these effects summate under certain conditions the sensory resultant might be the enhancement of apparent brightness obtained in the Bartley effect. The probability of a neuro-muscular component in this effect is strengthened by Bartley's report of the emergence of definite sensations of ocular strain or tension coincident with the flash frequencies producing maximal enhancement of apparent brightness (4).

Present Investigation

In connection with an investigation of the effects of intermittent illumination upon certain performances of patients with cerebral lesions and of normal subjects (12) (13), an opportunity was afforded to secure information bearing directly upon the role of the intra-ocular musculature in producing the Bartley effect.

A normal subject, age 22, with bilateral mydriasis (8 mm pupils produced by scopolamine, 0.5 percent) for routine refraction was examined in two sittings under conditions described by Bartley as producing the maximal enhancement effect (3). Since Cushny (8) has shown that scopolamine eliminates both accommodative and pupillary reflexes, any change of apparent brightness at any frequency of intermittent light could not be due to either of these mechanisms.

Method

The relation of apparent brightness to flash frequency was investigated by means of two equal-sized circular fields (2.25° with subject at 1 meter) separated 25° on the horizontal axis of the visual field. One of the fields was steadily illuminated and the other intermittently, at rates from 4.2 to 42 per second. The intensity of the steady field was fixed at 22 foot-lamberts; that of the intermittent field was variable through 5 to 50 foot-lamberts. The light-dark ratio was 1/1. The fields were viewed binocularly.

The subject was required to adjust at leisure the intensity of the intermittent field to appear equal to the steady field. The subject was instructed to look first at one and then at the other of the two fields in making comparisons. This was necessary to avoid fixation by the subject of an imaginary point between the two. For patients with cerebral lesions, we have found it necessary to determine objectively that successive fixation has occurred by simultaneously recording eye movements (11).

Preliminary trials were given with the intermittent field well below fusion and with the intensity of the two fields brought to physical equality before and after each trial. This aids untrained observers in the establishment of a stable criterion of judgment before the beginning of the experiment proper.

The flash rate was set at various values and a group of three readings was secured for each during a given series. In one series the intermittent field was to the right (subject's) and in the other it was to the left. The values obtained for each flash frequency were combined from the two series and averaged in plotting the results shown in Fig. 1. Mydriasis was checked before and after each series.

Results

As may be seen in Fig. 1, the results exhibit the effect of enhancement of apparent brightness at flash frequencies in the region of 8 to 10 per second as described by Bartley (3). It may be seen further

that in the region producing maximal enhancement of the intermittent field, approximately half of the luminous flux of the steady field is required to equal it in apparent brightness. In the region of fusion (Talbot effect) approximately twice as much luminous flux is required to equal the steady field. In other words, the magnitude of the maximal enhancement effect in the present findings is substantial and approaches the reciprocal of the Talbot effect in apparent brightness value. This is the relationship described by Bartley.

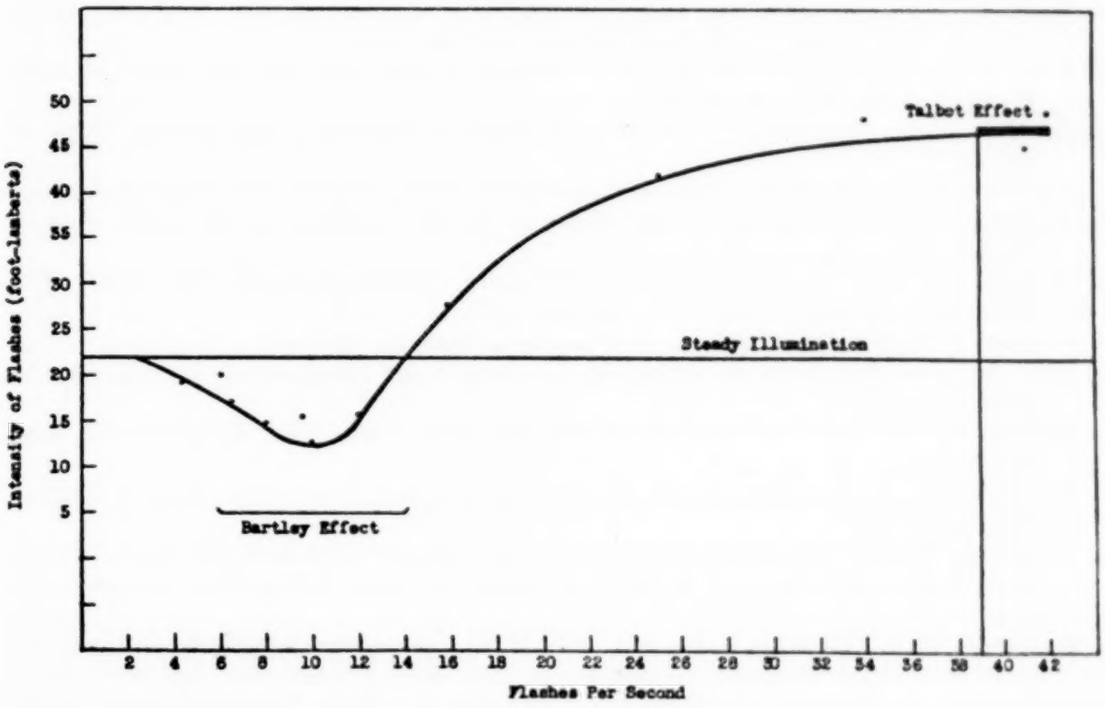

FIG. 1. Curve showing the relationship of apparent brightness of an intermittent field to a steady field as the flash rate is reduced from critical flicker frequency to near zero frequency or continuity, with pupillary and accommodative mechanisms eliminated by scopolamine; the relation between the Bartley and the Talbot Effects. As flash rate is reduced, the average brightness of the intermittent field increases until it equals then exceeds the steady field. In the region of 8 to 10 flashes per second maximal enhancement of brightness is reached at a value approaching the reciprocal of the Talbot brightness. This is the relationship described by Bartley, 1938 (3).

COMMENT AND SUMMARY

The results indicate that the Bartley effect, enhancement of apparent brightness of intermittent light, is not produced by the pupillary or accommodative mechanisms since it may be operative when these two mechanisms have been effectively eliminated (mydriasis produced by scopolamine) as sources of variation in the visual system.

It is of interest that our subject reported (spontaneously or under questioning) no sensations of ocular strain or tension. Since these are commonly experienced under usual conditions of observation of

the Bartley effect, particularly as the flicker rate approaches the region producing maximal enhancement of apparent brightness, it seems probable that the origin of such sensations may safely be attributed to the intra-ocular musculature.

(Manuscrpt received December 9, 1940)

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EFFECTS OF BENZEDRINE SULFATE ON PERFORMANCE IN TWO TESTS OF HIGHER MENTAL FUNCTIONS

BY R. HECHT AND S. S. SARGENT

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Many studies of the effects of benzedrine sulfate upon mental functions have appeared in the last five years (**2**, **6**). A study by Sargent and Blackburn in 1936 (**5**) caused a sensation by reporting a rise of over 8 percent in intelligence score after ingestion of 20 mg. of benzedrine sulfate. Subsequent studies have failed to discover such striking effects, but it has often been reported that benzedrine sulfate reduces errors and sometimes that it heightens learning ability (**2**, pp. 10–11). Such improvements have been attributed not to an augmentation of intelligence or brain capacity but rather to a general facilitation of the central nervous system, and increase in confidence, diminution of fatigue, etc.

After investigating the effects of benzedrine sulfate on performance in a comprehensive psychometric examination, Carl and Turner (**3**) conclude that "moderate (10 mgm.) dosage of benzedrine produces a tendency toward accelerated reaction in psychomotor output, so long as the execution of the actual physical movements does not require thinking or deliberation." They found that the drug had little if any effect on rote memory as tested by immediate recall. "Where more complex memory functions, involving analysis, deliberation, 'thought,' or integration of elements are concerned, the situation is in doubt. . . ."

However, the battery of tests used by Carl and Turner contained few tests of higher mental processes, in the sense of thinking, reasoning or problem-solving. It seemed worth while to see whether the drug might affect these activities differently from those involved in the more usual psychometric tests, so a test of reasoning and one of thinking or problem-solving were selected for investigation. While experimentation was in progress a study was published by Andrews, entitled 'The Effect of Benzedrine Sulfate on Syllogistic Reasoning.' In it the author reported no significant effect by the drug upon reasoning scores, though all the changes found indicated a slight, statistically unreliable, facilitation (**1**).

Materials and Procedure

The benzedrine sulfate used in this experiment was in the form of 10 mg. tablets. Lactose placebo tablets, identical in size, shape and color with the benzedrine were used for control purposes. Both were supplied by the courtesy of the Smith, Kline and French Laboratories in Philadelphia.

Two equated reasoning tests of fourteen items each were constructed from two experimental tests on reasoning kindly loaned by Professor L. L. Thurstone of the University of Chicago. One of the authors had previously used these Thurstone reasoning test items individually on a number of subjects. The equating was done by choosing for the first and second tests paired items which had been found equal in difficulty as measured by median time required for solution by sixteen subjects. Reliability, measured by uncorrected correlation between these parallel forms, was .82 ± .04.

It is hard to find reliable and well-standardized tests of thinking and problem-solving. The investigators finally decided to use the anagram, or disarranged word, problem, which had already been worked upon by one of them in a study of thinking processes (4). Solution of this type of problem involves considerable trial and error and 'insightful' behavior. Two parallel tests of twenty items each were constructed from pairs of disarranged words previously found to be equal in difficulty as shown by the performance of twenty subjects. Reliability of this test was .54 ± .07, a figure considerably below that of the reasoning tests; its index of reliability would, however, be .735.

Samples of items from the reasoning tests are:

James could run five times as fast as Johnny, and Harry could run five times as fast as Johnny. Could James run faster than Harry, or just as fast, or not as fast as Harry, or can't you tell?

Faster Same Slower Can't tell

If I have more than a quarter, I shall go either by taxi or by train. If it rains I shall go either by train or by bus. It is raining, and I have fifty cents. How do you think I shall go?

Taxi Train Bus Can't tell

John and James both walked from a town called A to a town called B. John went first to a town called C; and then, without stopping, he walked from C to B. But James walked on a road from A to B which did not go through C. Can you tell who went the shorter way?

John James Can't tell

Samples of items from the disarranged word tests:

RADOI	BARBIT
AMYLIF	MALONR
LYBIATI	VAHSRTE

Time limit on the reasoning tests was seven minutes; on the words test ten minutes. Score was the number of items correct.

Subjects for the experiment were day and evening students in Psychology classes at Central Y. M. C. A. College, Chicago, in the spring and summer of 1940. When divided into benzedrine, placebo and control groups, two-thirds to three-quarters of each group were men. After a student volunteered to be a subject he was given a blood-pressure and pulse test; those above or below the normal range were excluded. Next, to test for possible allergic reactions, each subject was given one-quarter of a tablet of benzedrine sulfate, followed a day or two later by half a tablet; only two or three students reported unpleasant effects and they were, of course, barred from further participation. Women students were told not to serve as subjects if the day on which the drug was to be administered fell within two days before or after their menstrual periods.

The subjects were divided into three groups—benzedrine, placebo and control; the groups were not physically separated, however, and subjects did not know, when they took the tests, that there were three such categories. Because of the insomniac effects of benzedrine when taken in the late afternoon or evening, day students were used for the benzedrine and placebo groups and evening students for the control group.

All students took the first reasoning and disarranged words test under normal conditions, *i.e.* without any drug or placebo whatsoever. The second tests were given just two days after the first. Immediately after taking their first tests, those subjects who were to be included in the benzedrine and placebo groups were reminded that they were to drink no coffee, tea, coca cola or any other stimulant on the day of the second tests. They were instructed to call at the Psychology Department office to get their tablets an hour before the tests were to begin—just prior to the regular one hour class period which preceded the administration of the second

tests.[1] None of these subjects knew that placebo tablets were being used; each subject thought the pill he swallowed was a benzedrine sulfate tablet, whether it actually was or not.[2] In the control group, of course, no tablets or other experimental factors were introduced before the second tests, which were administered under exactly the same conditions as the first test.

Results

Results are shown in the following table.

TABLE I

Changes in mean scores of three groups of subjects on two alternate forms of a reasoning and a disarranged words test, taken two days apart.

(Subjects in the benzedrine group took a 10 mg. tablet of benzedrine sulfate one hour before the second test; in the placebo group a lactose tablet, identical in appearance with the benzedrine tablet, one hour before the second test; subjects in the control group took no tablets before the second test.)

Reasoning

	First Test	Second Test	Difference
Benzedrine sulfate group (N 38)	8.66	8.34	−.32
Placebo group (N 21)	8.29	8.10	−.19
Control group (N 32)	8.75	8.25	−.50

Disarranged Words

	First Test	Second Test	Difference
Benzedrine sulfate group (N 38)	9.42	8.68	−.74
Placebo group (N 21)	9.00	8.62	−.38
Control group (N 32)	9.16	8.88	−.28

None of these changes in score from the first to the second test was statistically significant; the largest critical ratio had a value of less than 1.00. Nor were any noticeable differences in speed or efficiency encountered. It will be noted from the control group scores that the second form of both the reasoning and disarranged word tests is more difficult than the first. The score of the benzedrine group (and also the placebo group) in the reasoning test went down

[1] Estimates on the proper interval to allow between ingestion of the tablet and testing vary from half an hour to two or three hours. After consulting a physician and a physiologist the experimenters chose one hour as a plausible interval.

[2] When there is a control group, with which to compare the results of both experimental and placebo groups, this procedure seems better standardized than the one in which subjects in both groups are told they may be taking either a genuine drug or a lactose tablet.

less than that of the control group. This might be cited as evidence of a slight, though unreliable facilitative effect from benzedrine (or the assumption that benzedrine had been given), which agrees with the findings of Andrews. But in the disarranged words test the benzedrine group (and to a lesser extent the placebo group) lost slightly more than the control group. It seems clear that, judging from these two types of test material, we may say that benzedrine sulfate has no reliable or consistent facilitative or inhibitory effects upon higher mental functions.

Concluding Remarks

Introspective data were not collected in this study. However, the reports and comments of some of the subjects, the observations of the investigators, and some acquaintance with studies of the effects of benzedrine suggest two conclusions about the most profitable directions for future research.

First, more attention should be given to individual differences. Some individuals cannot take benzedrine at all; why then is it not likely that with some subjects 10 mg. is an optimal dose, with others 20 mg. and still others 30 mg.? One subject reports no noticeable effect from the drug until about three hours after ingestion; another finds different symptoms within half an hour after taking a tablet. In the present study variability was high; with a mean score of eight or nine the standard deviation was about three. It is quite possible that some subjects within our benzedrine group were facilitated and others inhibited by the same 10 mg. dosage of the drug. Group methods reveal these differences inadequately, if at all. Physicians have to study individual physiological reactions to drugs; why should not the psychologists follow their lead in making clinical studies of the psychological effects?

Second, more should be known about the work methods and the mental processes comprising an individual's behavior as he takes a test. A subject who works at a problem in a logical analytical way may be affected by experimentally introduced factors differently from a subject who solves the same problem in a non-analytical way. Many mental tests involve a wide variety of operations and sample various mental functions; it is difficult to know which function or functions are affected by a given experimental influence. The more specific the function being tested, the clearer the effect of a drug. Tests of more or less unitary primary abilities are being developed, so it should soon be possible to study the effects of drugs upon fairly well understood verbal, numerical, spatial, memory and other abilities.

(Manuscript received November 26, 1940)

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AN EXPERIMENTAL SET-UP FOR THE INVESTIGATION OF LANGUAGE PROBLEMS

BY JOHN BUCKLEW

Indiana University

In the psychology of language behavior there exists a whole class of problems which can be attacked readily with modifications in already existing apparatus and techniques. In order to investigate some of these, the writer has attempted to set up a laboratory situation involving the listener's response to spoken language. This requires the introduction into the laboratory of a language situation conforming as closely as possible to certain situations involved in normal speech. In concrete speech there are two major stimulus variables operating—the speech, and the thing or things spoken about. Both of these variables can be set up in the laboratory so as to control and measure them, and to determine their effect on the listener's response.

For the present procedure, sentences composed of statements about common things (squares, circles, letters of the alphabet, etc.) are recorded on a phonograph record and reproduced at definite intervals through a loudspeaker. The voltage initiated by the beginning of the speech is picked up from the amplifier of the phonograph and conducted to a second amplifier in an independent circuit. The latter is coupled by means of a transformer to a circuit containing a cold cathode gas triode tube which has been set just below the discharge point (Diagram 1). The use of this type of tube in connection with voice reaction time has been described recently by Hamburger (**2**). This newly developed tube is valuable as an economical and reliable means of starting and continuing the operation of a timer. The tube is set so that a slight increase in voltage (such as that caused by a voice speaking through a microphone) will break down its resistance and allow a continual electrical current to pass until the circuit is broken.

The closing of the cold cathode tube circuit may be utilized to throw a relay switch and run a timer. In the present experimental set-up the purpose is to clock the time from the beginning of the speech on the phonograph until the subject responds by pressing one of two keys. These keys are wired in series so as to break the cold cathode tube circuit. Once broken, the cold cathode tube will not re-discharge until its resistance is again overcome by the next sentence.

The time lag of this method, exclusive of the chronoscope used, should be small, since no mechanical movements beyond that of the relay are involved. However there is some question of the sensitivity of the cold cathode tube to the consonant sounds. Any vowel sound, if reproduced at normal speech loudness, is amply sufficient to kick over the tube, but consonant sounds often do not have many more decibels of loudness than normal surface scratch. Thus setting the tube to a degree of sensitivity sufficient for consonant sounds involves the danger of closing the timer circuit prematurely due to surface noise on the record. Time lag from this source, however, should be small and fairly constant.

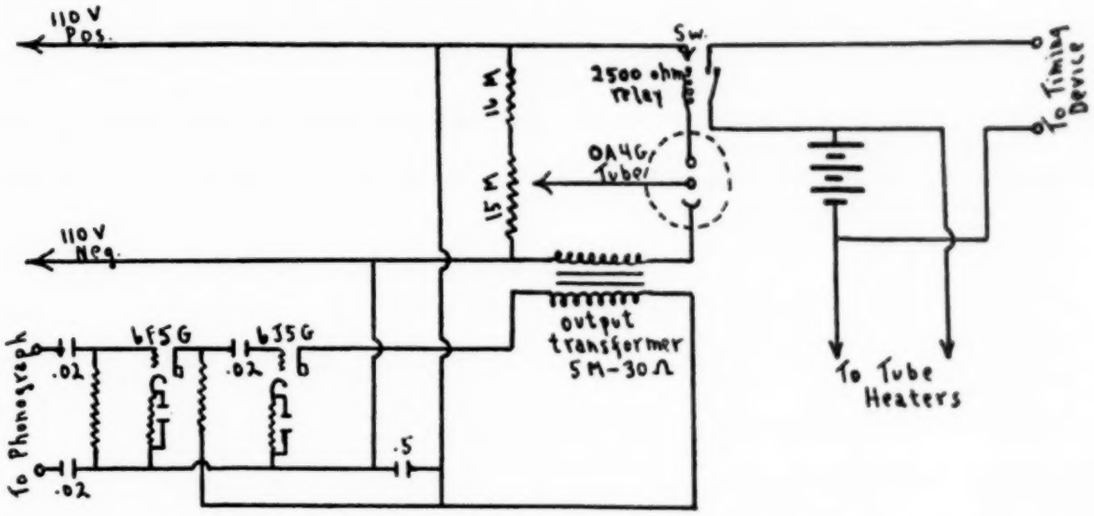

DIAGRAM 1. Method of wiring in order to utilize a cold cathode tube for the operation of a timer in conjunction with a phonograph record.

The use of a phonograph record is essential to insure the sentence being reproduced for each subject with the same speed and clearness. If necessary, the duration of the sentences can be measured by means of an oscillographic recording.

The second variable in a speech situation, the thing spoken about, consists in this case of dark gray cardboard slides with various geometrical figures, letters, or numbers cut in them. These slides are exposed by placing them in a simple exposure apparatus consisting of a tin box with an electric light inside and a frosted plate glass screen in front. The slides are inserted just back of the frosted glass. The shades of gray are so arranged that the cut out portions of the slides are invisible to S until the light in the box is turned on by E. When the light is switched on the figures spring into bright relief against the frosted glass. Thus the appearance of this stimulus and its duration may be controlled by E. In front of the exposure box are the two telegraph keys, one marked 'true' and the other 'false,' either of which will stop the timer and furnish a reading for the event.

The total situation is as follows. The sentences recorded at intervals on the phonograph record consist of statements made about the slides being exposed to S. S may respond by pressing the 'true' or 'false' key depending upon the correspondence between the statement and the slide exposed. Changes such as speech distortion or delay in the appearance of the slide may be introduced in order to study the effect on the auditor response. This procedure allows full control of the unique feature of language—namely the operation of two interrelated variables, the speech and the things spoken of. Correlation of results with other known psychological phenomena may of course be carried out.

(Manuscript received December 9, 1940)

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